Introduction to Artificial Intelligence

丁尧相
浙江大学

Fall & Winter 2022
Week 1

Outline

- Course Info
- What is AI?
- Three building blocks:
  - Decision making
  - Knowledge reasoning
  - Machine learning
- Two term goals
  - Decode math equations
  - Play Atari games
- Take-Home Messages

Outline

- Course Info
- What is AI?
- Three building blocks:
  - Decision making
  - Knowledge reasoning
  - Machine learning
- Two term goals
  - Decode math equations
  - Play Atari games
- Take-Home Messages

Course Info

- Time:
  - Monday 6-8 (every week), 西1-416
  - Wednesday 11-12 (lab, double week)

- Instructor: 丁尧相 yaoxiangding@gmail.com
  - Office Hour:
    - Wednesday 15:00 -17:00, Meng Minwei Bldg. 519
    - Better to make appointment on Ding Ding

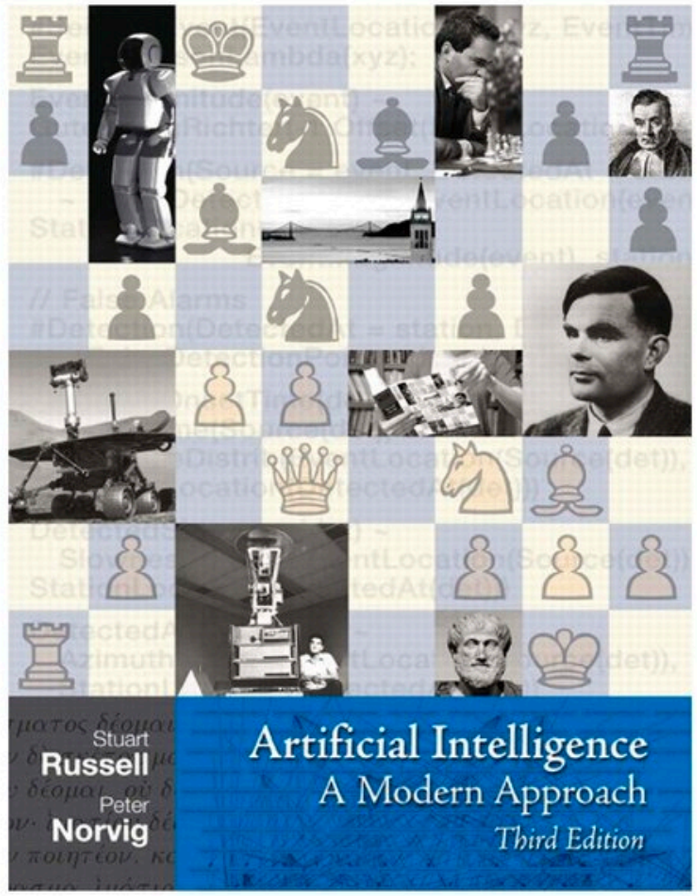
- TA: 彭奕飞 buweishengrenjiweiqinshou@gmail.com

- Course homepage: https://yaoxiangding.github.io/AI-course.html

Schedule

- 16 weeks
  - 14.5 lectures (.5 due to the mid-term test)
  - 7 labs
- Grading: 70% knowledge part + 30% lab part
  - Knowledge part:
    - Four problem sets 40%
    - Mid-term test 10% & final exam 50%
  - Lab part:
    - 4 projects
    - 4 bonus score for the final grading (details later)

Textbook



- The textbooks are not required. We will put the necessary materials on the course homepage.

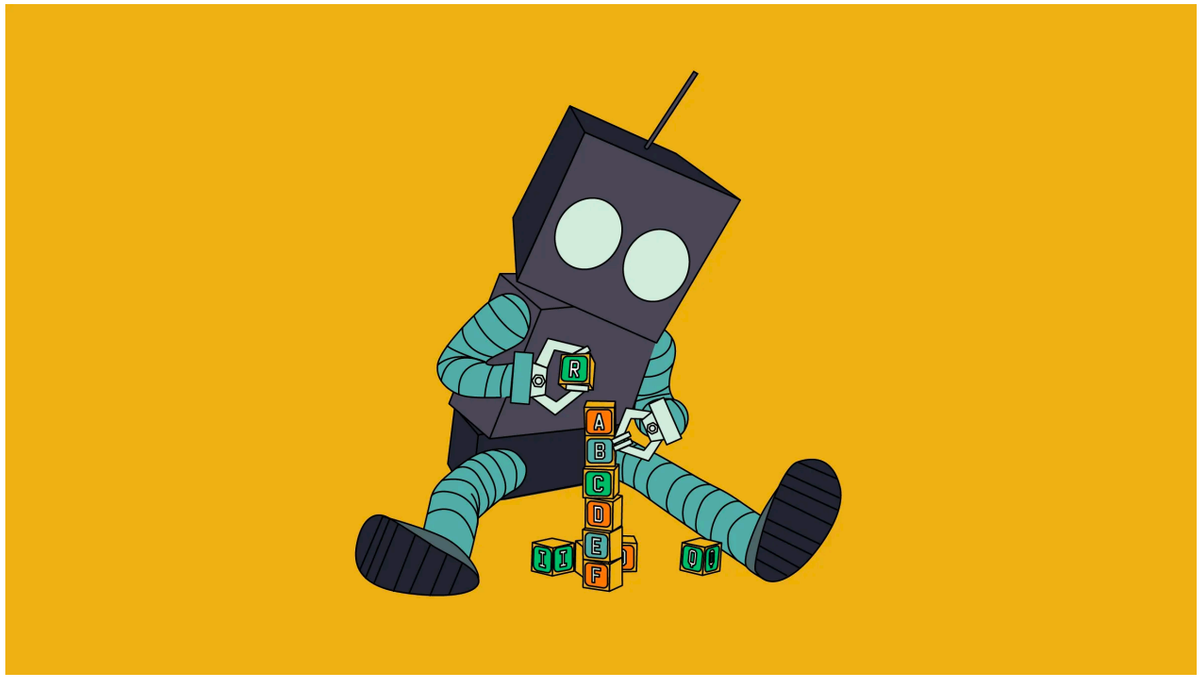
Outline

- Course Info
- What is AI?
- Three building blocks:
  - Decision making
  - Knowledge reasoning
  - Machine learning
- Two term goals
  - Decode math equations
  - Play Atari games
- Take-Home Messages

Artificial Intelligence

"Definitions demand reduction and reduction demands going to a lower rung."

— Judea Pearl, "The book of why".

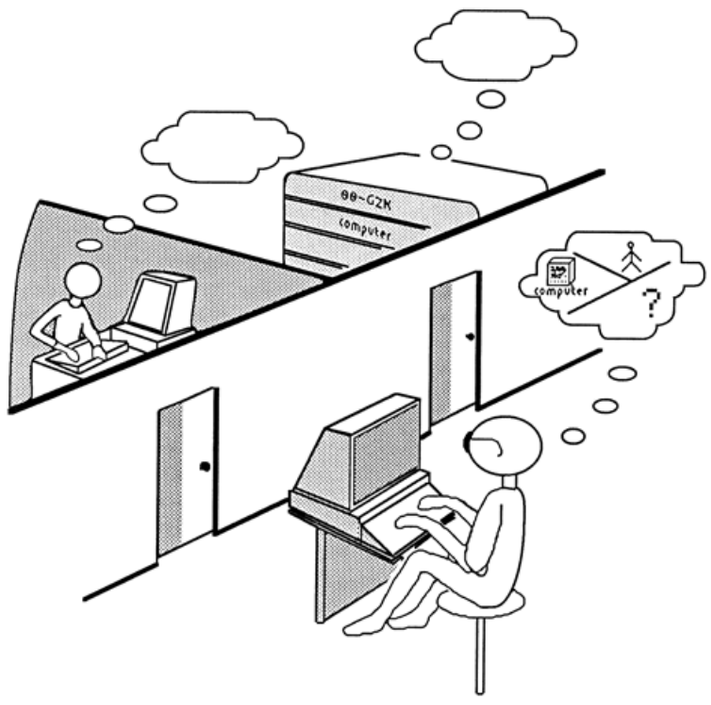


Turing Test

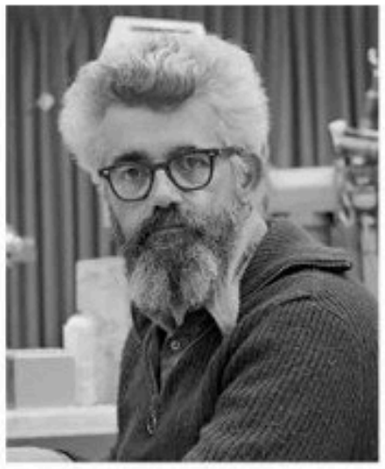
"The new form of game can be described in terms of a game which we call the 'imitation game' ".

"Instead of trying to produce a programme to simulate the adult mind, why not rather try to produce one which simulates the child's?

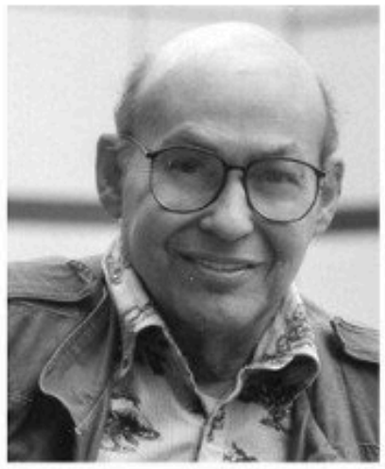
— Alan Turing, "Computing Machinery and Intelligence", 1950.



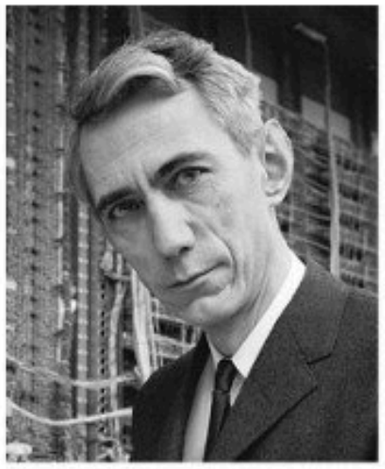
Dartmouth Conference (1956)



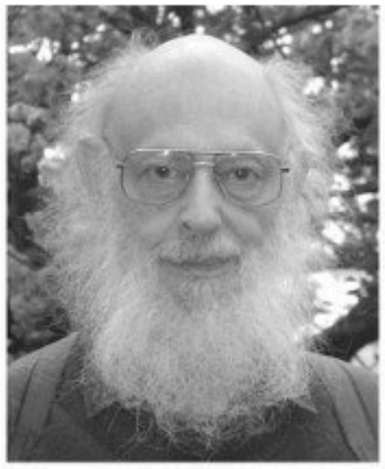
John MacCarthy



Marvin Minsky



Claude Shannon



Ray Solomonoff

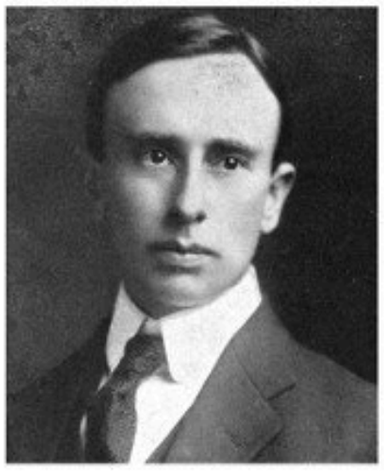
Alan Newell

Herbert Simon

Arthur Samuel

Oliver Selfridge

Nathaniel Rochester



Trenchard More

Dartmouth Conference (1956)

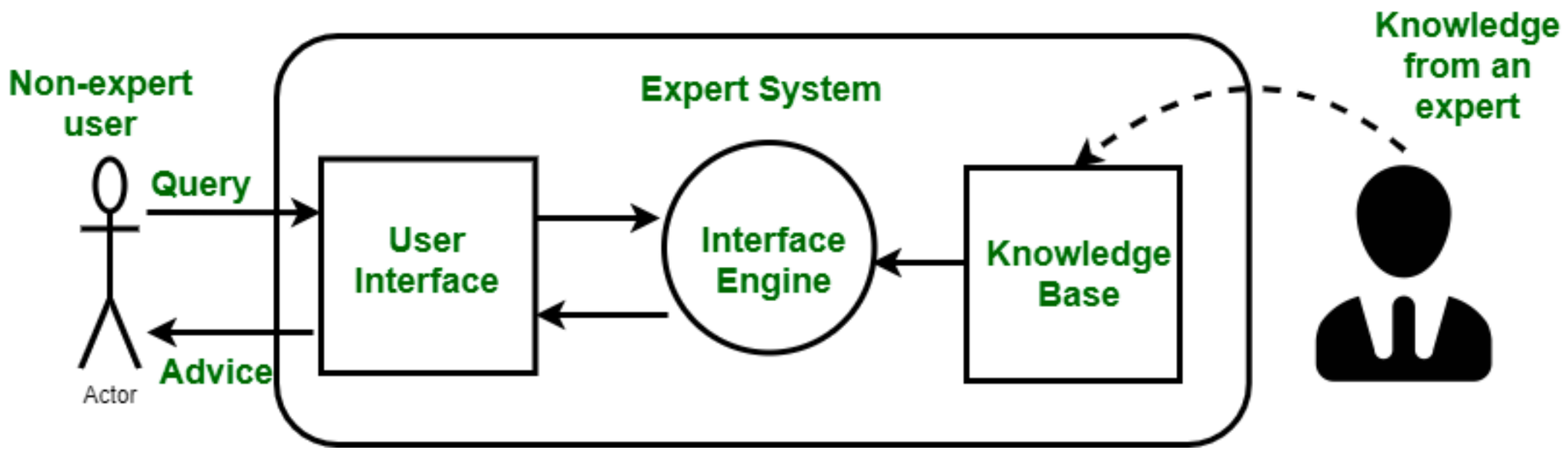
50 years later

Stage I: Problem Solving & Symbolic Reasoning (1950s-1960s)

- Newell and Simon's "Logic Theorist" and "General Problem Solver".
  - "We have invented a computer program capable of thinking non-numerically, and thereby solved the venerable mind-body problem."
- McCarthy's LISP language.
- McCulloch-Pitts neuron model (1940s) and Rosenblatt's Perceptron algorithm.
- The first AI winter (1970s)

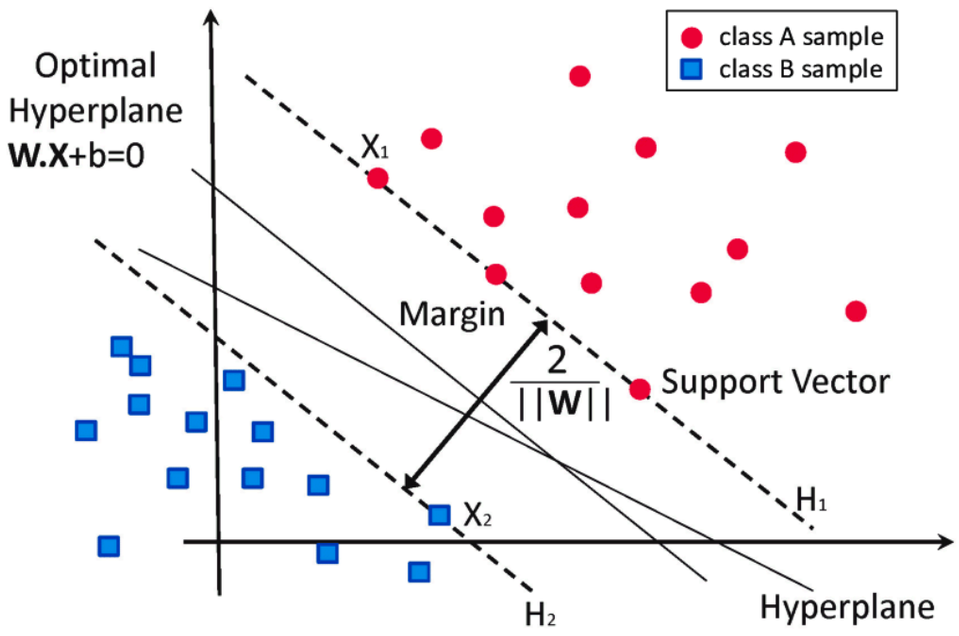
Stage II: Knowledge and Uncertainty (1970s-1980s)

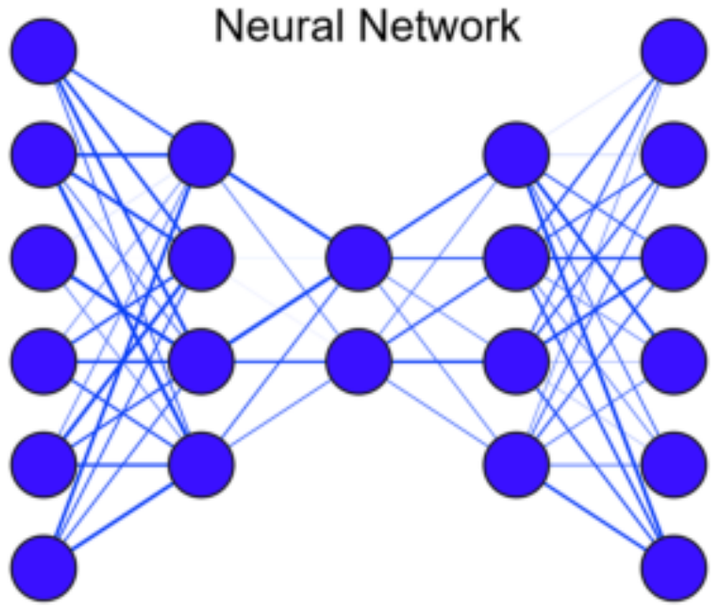
- Domain-specific knowledge system: expert system
- Reasoning under uncertainty: probabilistic modeling, graphical models
- (maybe) The second AI winter: (late 1980s - early 1990s)



Stage III: Machine Learning (1990s-Now)

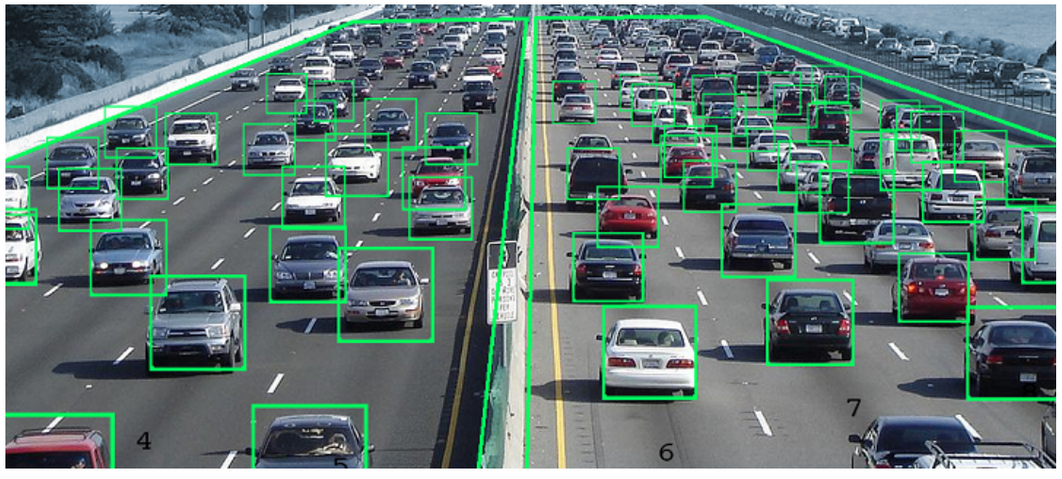
- The rise of statistical learning (root back to 1970s)
- The boost of deep learning (2006-Now)





Application Fields

- Computer vision
- Natural language processing
- Speech Recognition
- Robotics
- …



Connections to Other Fields

- Cognitive science, neuroscience, psychology
- Game theory
- Control theory, cybernetics
- ...

Connections to Other Fields

- Cognitive science, neuroscience, psychology
- Game theory
- Control theory, cybernetics
- …

If we still need a definition for AI…

AI is a subfield of computer science with connections on many other fields.
The goal is to build machines that think and act rationally and intelligently.

What Will You Learn in This Course?

- What won't you learn in this course? (apologize :-P)
  - computer vision, natural language processing, robotics
  - neural science, cognitive science
  - fancy applications

- What will you learn in this course?
  - The core techniques that allow machines to:
    - Obtain insightful knowledges via their own imperfect perceptions.
    - Make rational decisions in a complicated and uncertain world.

Build a routine that guides you to the frontier of AI.

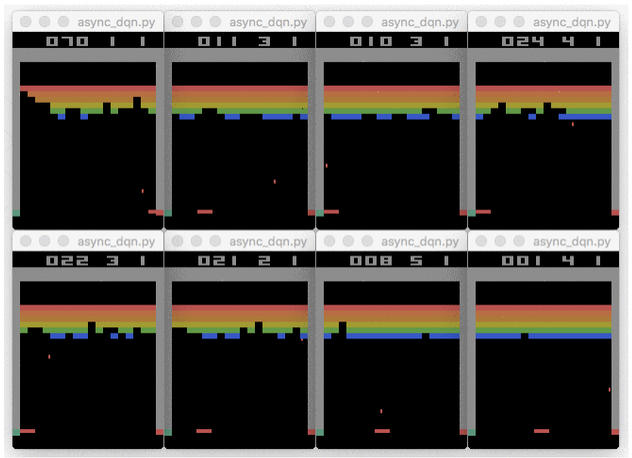
Outline

- Course Info
- What is AI?
- Three building blocks:
  - Decision making
  - Knowledge reasoning
  - Machine learning
- Two term goals
  - Decode math equations
  - Play Atari games
- Take-Home Messages

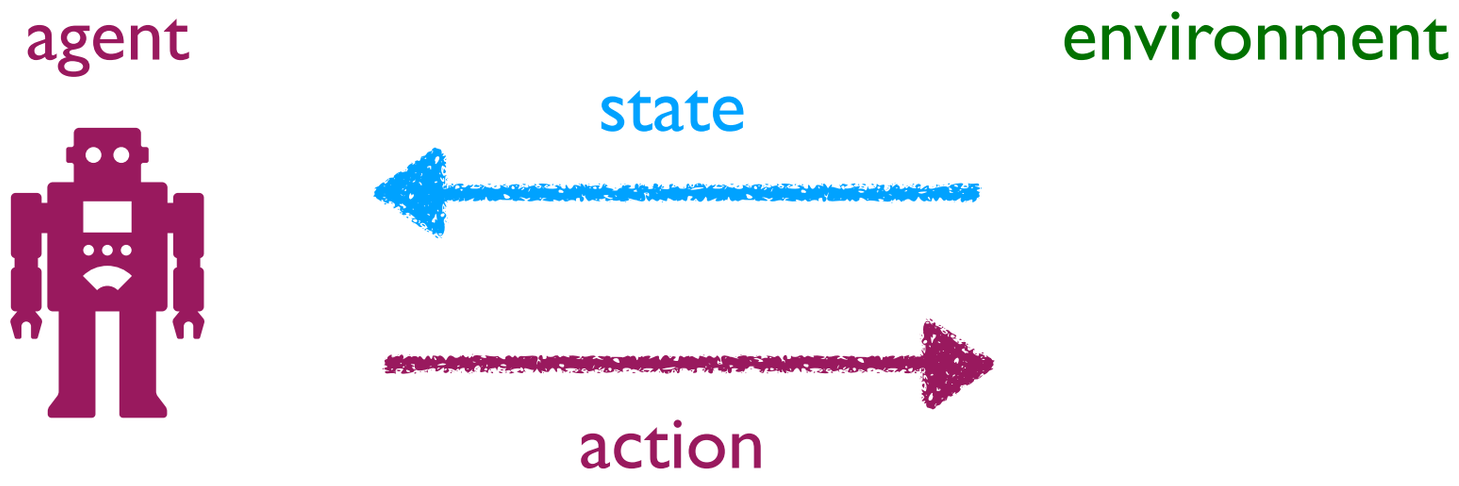
Outline

- Course Info
- What is AI?
- Three building blocks:
  - Decision making
  - Knowledge reasoning
  - Machine learning
- Two term goals
  - Decode math equations
  - Play Atari games
- Take-Home Messages

Decision Making

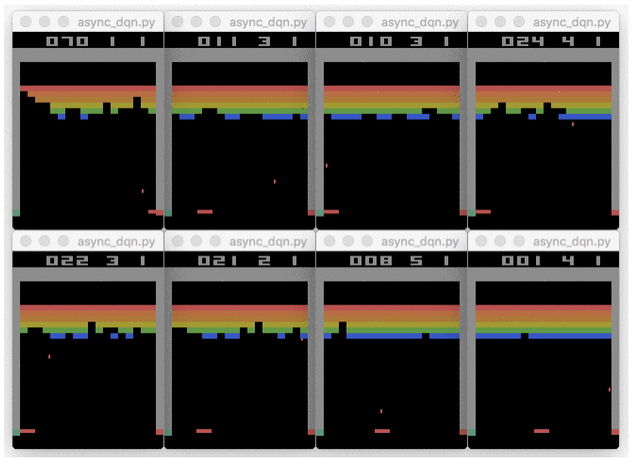


- Conduct action in any state of an environment.

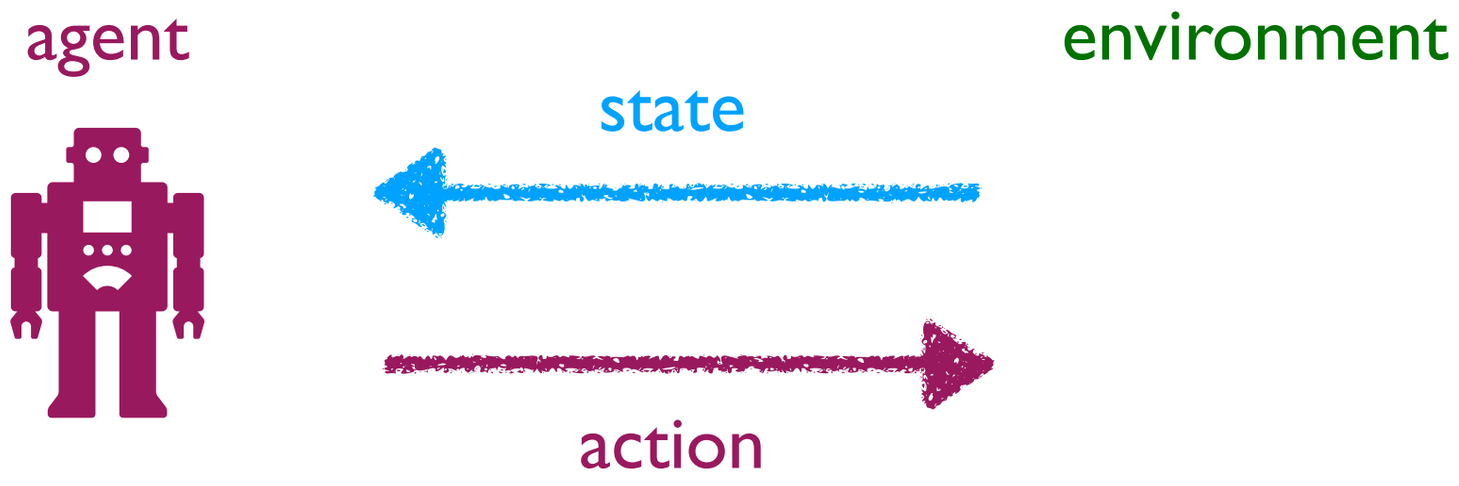


In most problems, the agent needs to do a sequence of actions w.r.t. a sequence of states.

Decision Making

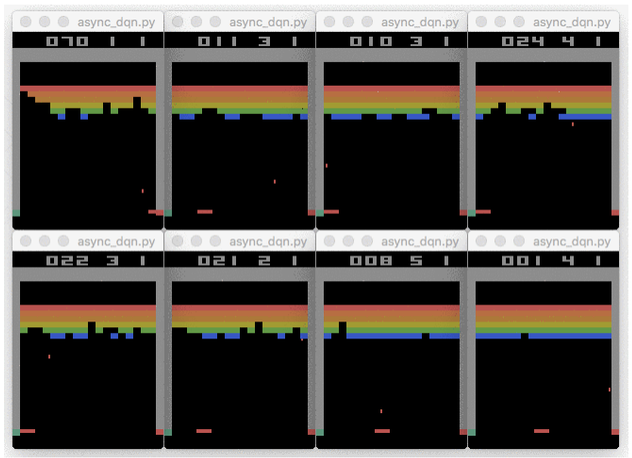


- Conduct action in any state of an environment.

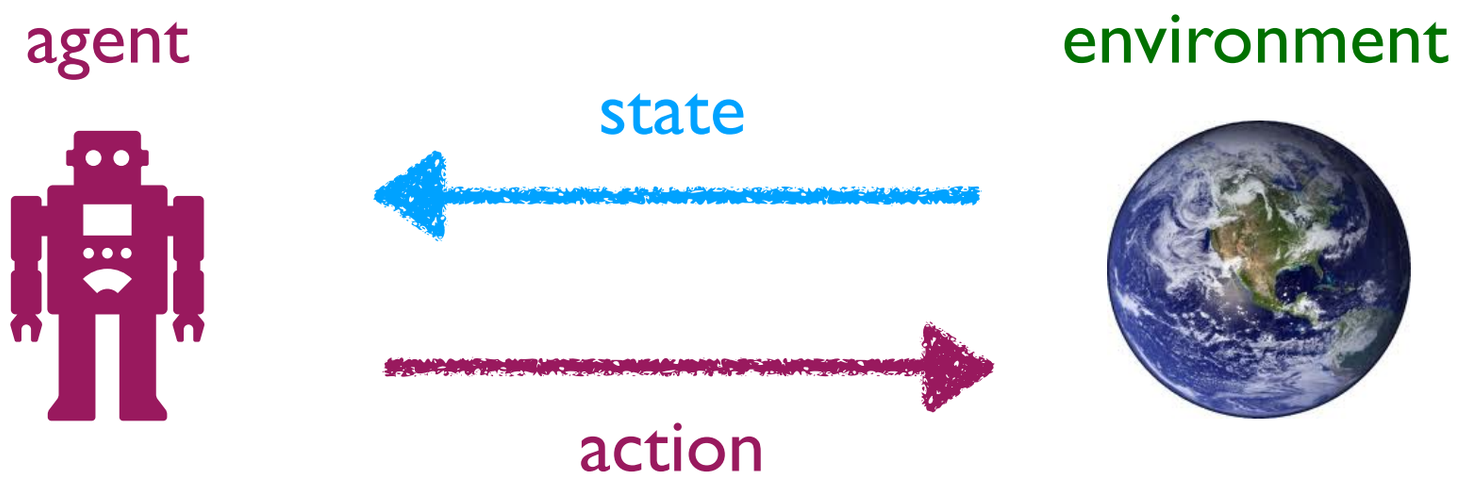


In most problems, the agent needs to do a sequence of actions w.r.t. a sequence of states.

Decision Making

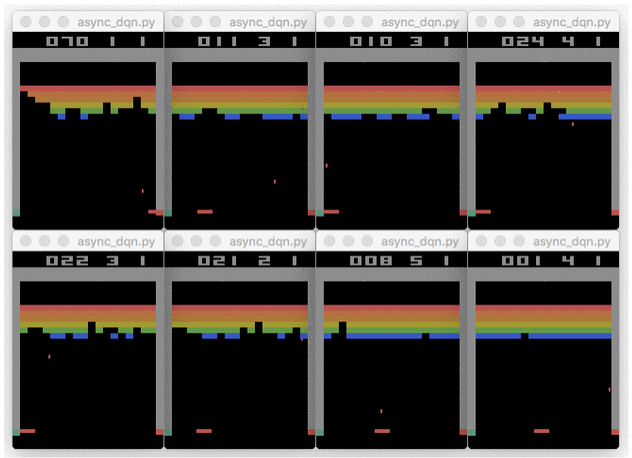


- Conduct action in any state of an environment.

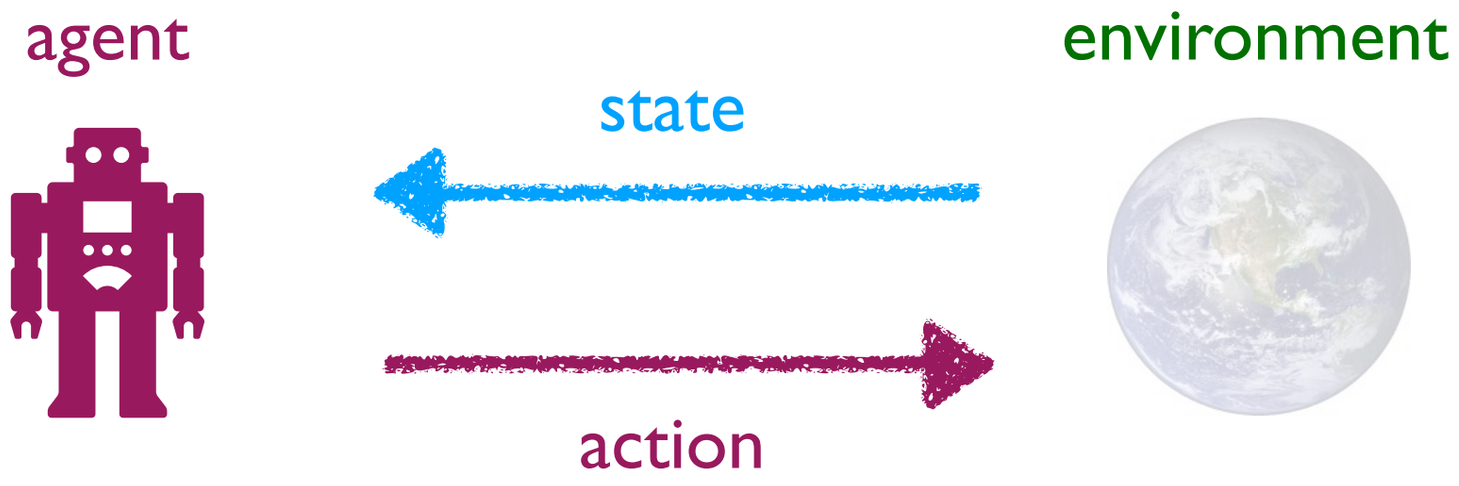


In most problems, the agent needs to do a sequence of actions w.r.t. a sequence of states.

Decision Making



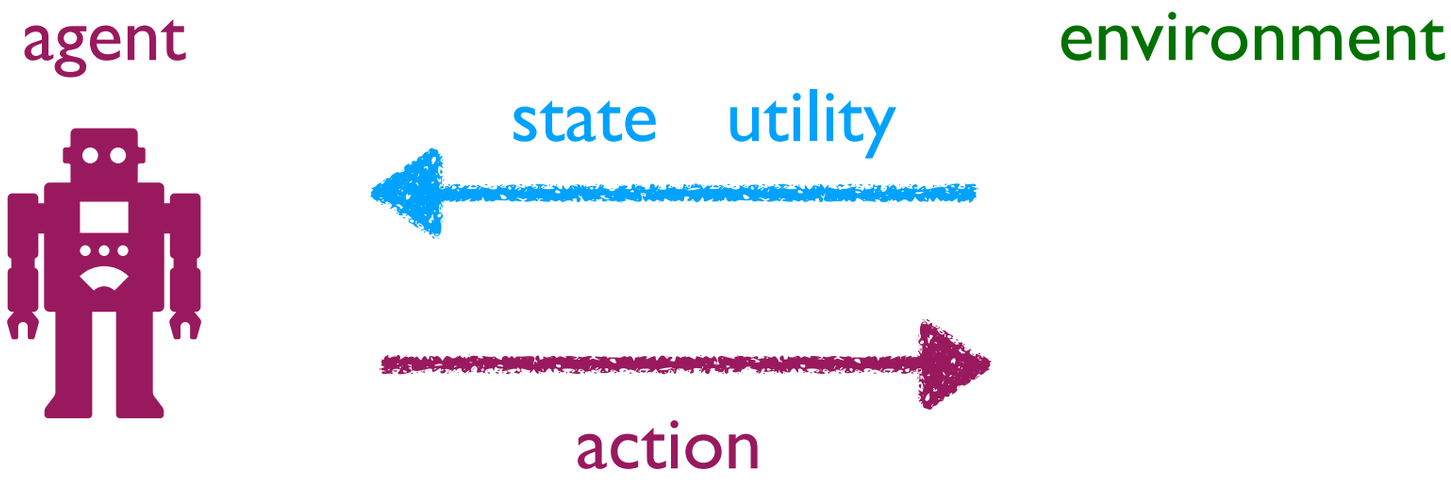
- Conduct action in any state of an environment.



In most problems, the agent needs to do a sequence of actions w.r.t. a sequence of states.

Goal & Utility

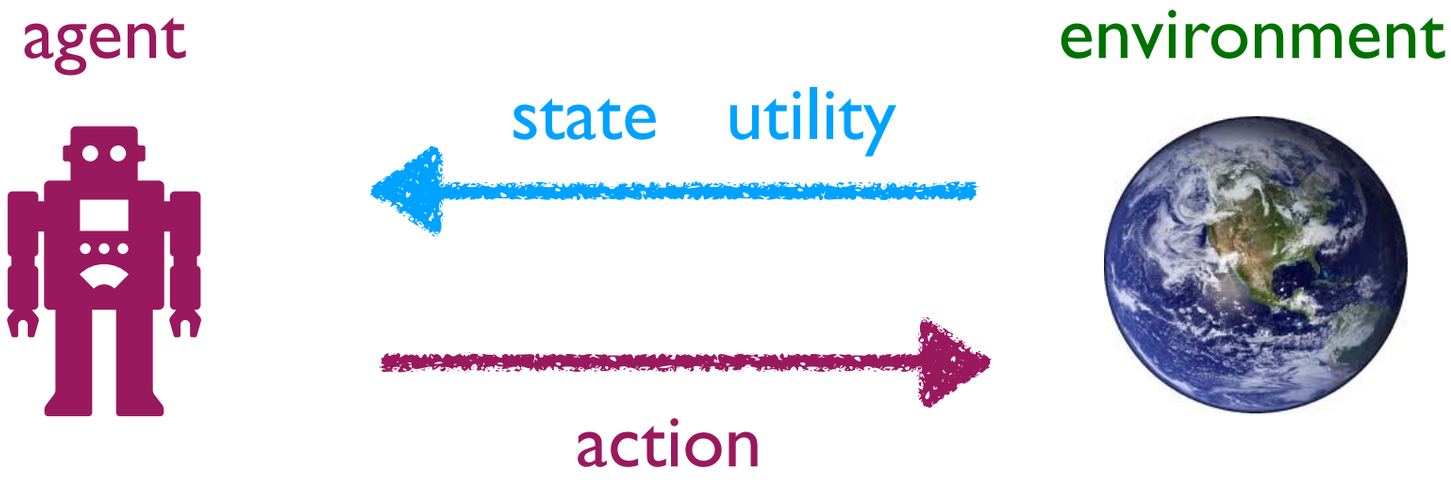
Goal & Utility



- What is the best actions that the agent can take?
  - Reach a goal with the minimal cost.
  - Obtain the most accumulative utilities along the sequence.

Goal-reaching and utility-maximizing agents are rational.

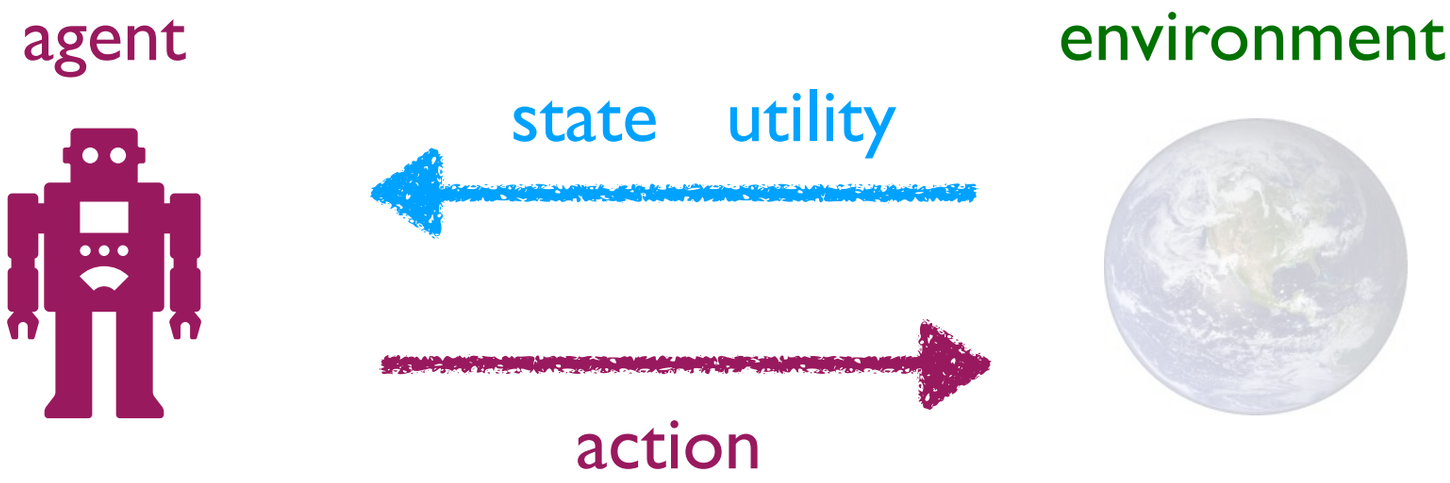
Goal & Utility



- What is the best actions that the agent can take?
  - Reach a goal with the minimal cost.
  - Obtain the most accumulative utilities along the sequence.

Goal-reaching and utility-maximizing agents are rational.

Goal & Utility

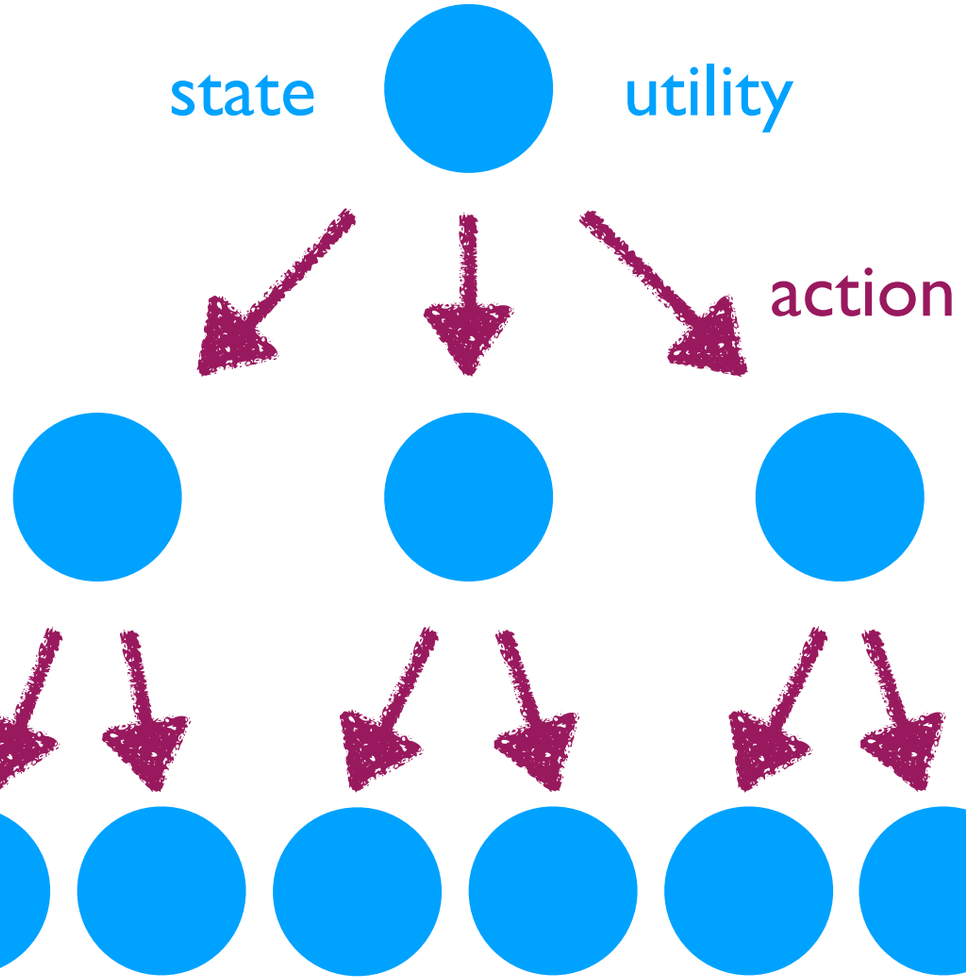


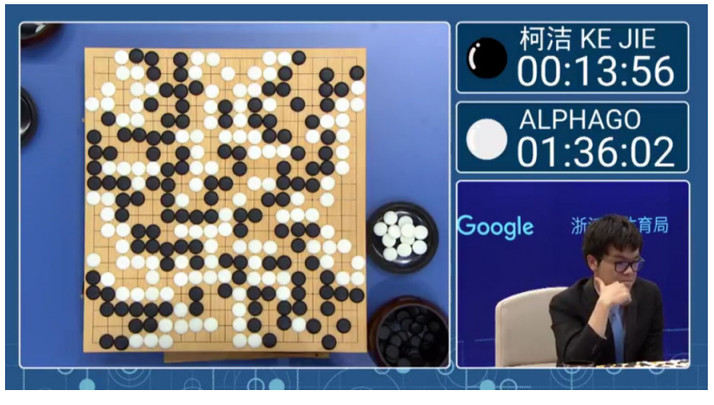
- What is the best actions that the agent can take?
  - Reach a goal with the minimal cost.
  - Obtain the most accumulative utilities along the sequence.

Goal-reaching and utility-maximizing agents are rational.

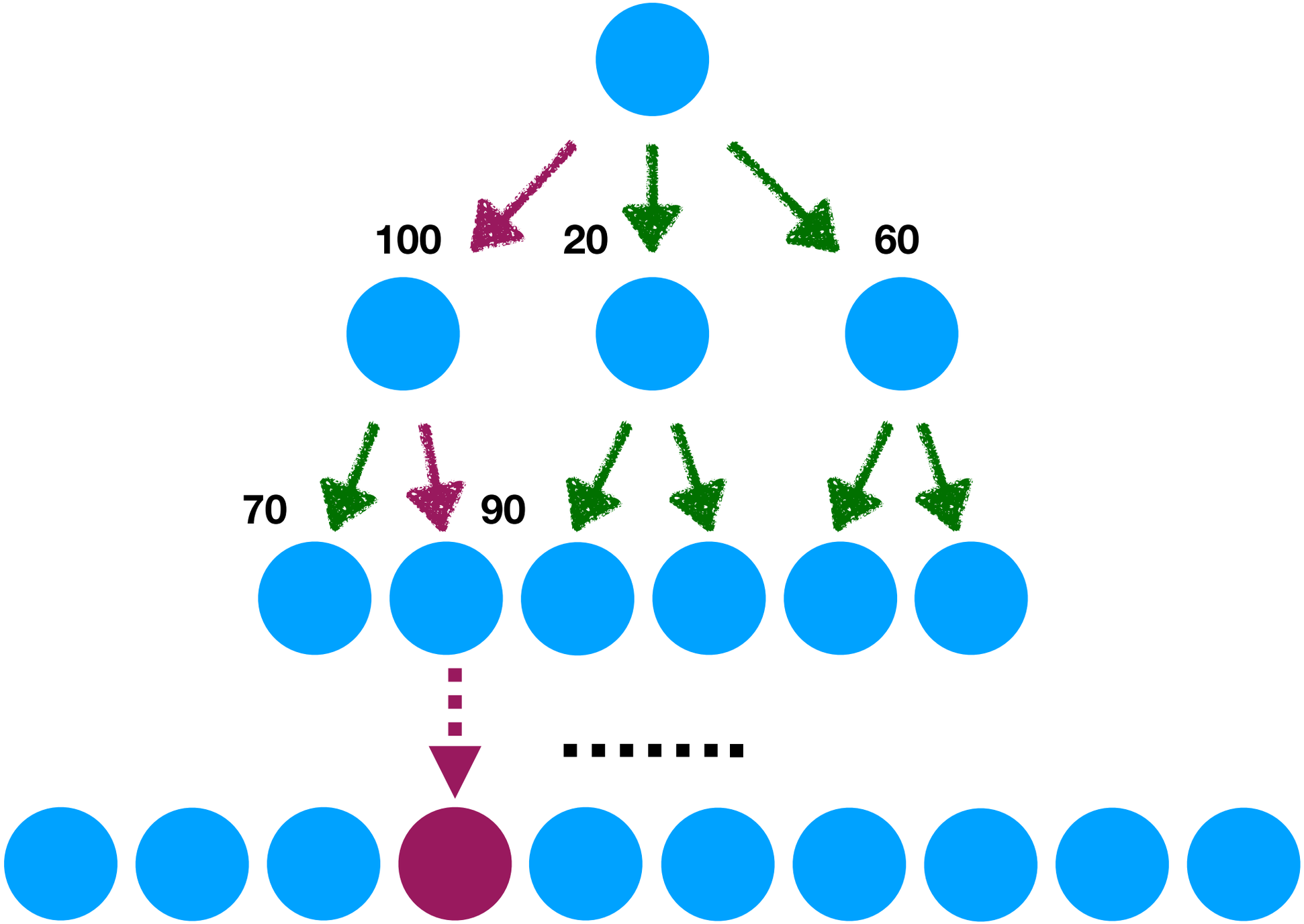
Model of Decision Making

Tree is the best friend
for computer scientists!





Search: the Basic Strategy for Decision Making

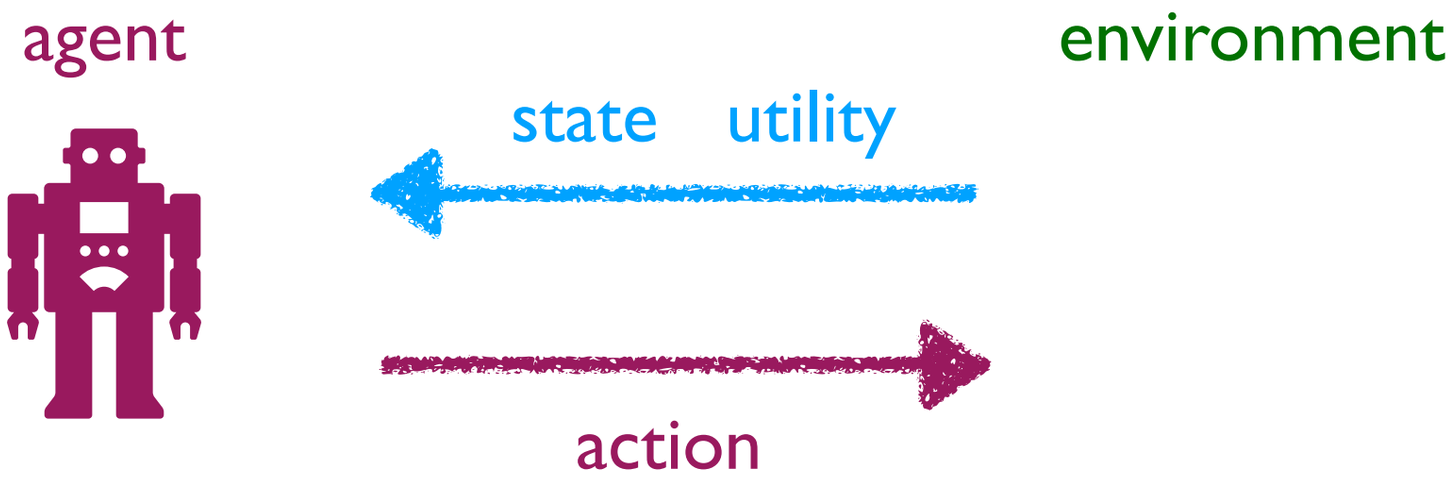


Challenges for Search Strategy

Personal perspective: Decision making is the central problem for AI.
But why strong AI is not reached when the machines can do search?

In most real AI problems,

- Search may not be computational tractable.
  - We will learn many strategies to do search smartly.
- The model (environment) may not be fully known by the agent.
  - The agent should build the model by itself.

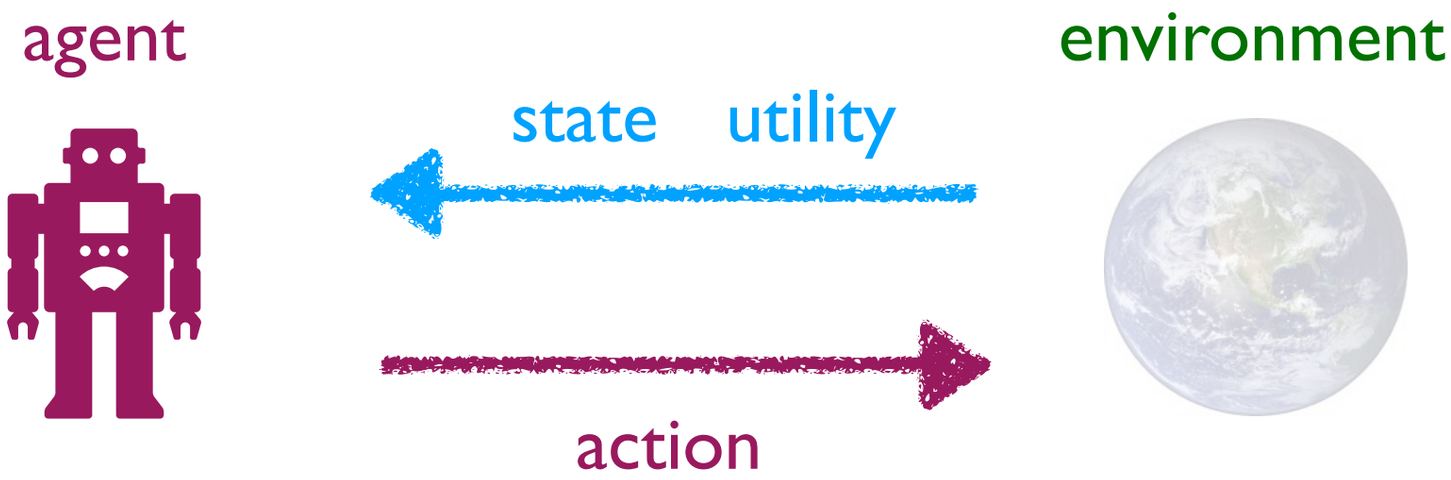


Challenges for Search Strategy

Personal perspective: Decision making is the central problem for AI.
But why strong AI is not reached when the machines can do search?

In most real AI problems,

- Search may not be computational tractable.
  - We will learn many strategies to do search smartly.
- The model (environment) may not be fully known by the agent.
  - The agent should build the model by itself.

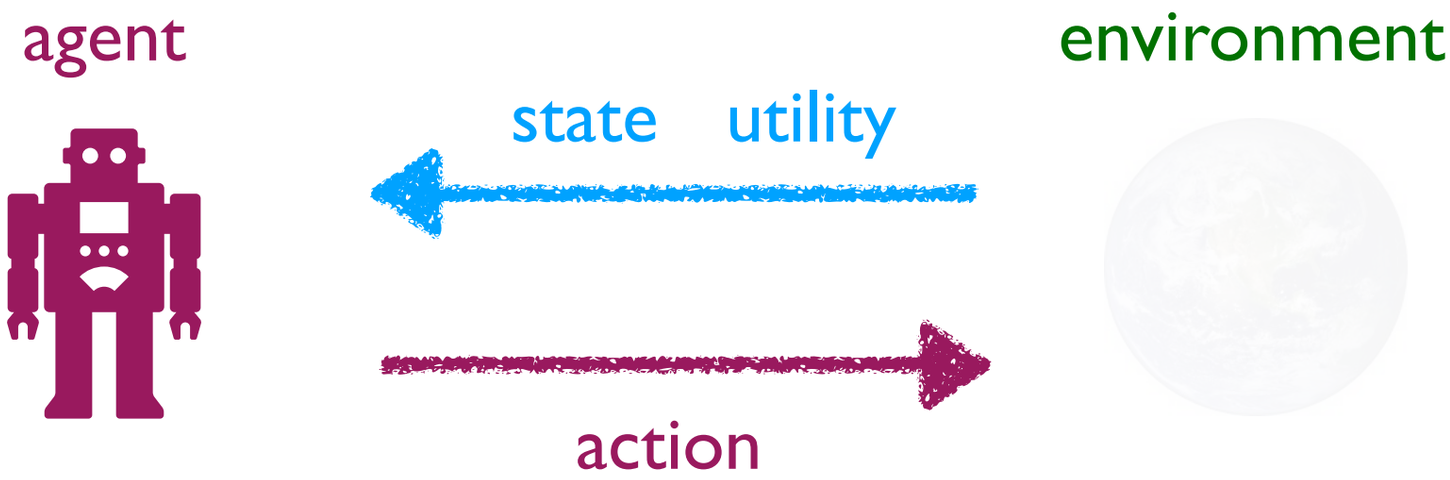


Challenges for Search Strategy

Personal perspective: Decision making is the central problem for AI.
But why strong AI is not reached when the machines can do search?

In most real AI problems,

- Search may not be computational tractable.
  - We will learn many strategies to do search smartly.
- The model (environment) may not be fully known by the agent.
  - The agent should build the model by itself.



Outline

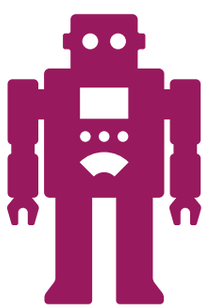
- Course Info
- What is AI?
- Three building blocks:
  - Decision making
  - Knowledge reasoning
  - Machine learning
- Two term goals
  - Decode math equations
  - Play Atari games
- Take-Home Messages

Internal vs. External Model

Since the agent cannot fully know the external model,
it should build an internal model itself for decision making.

internal model

agent



partial state

utility

environment
external model

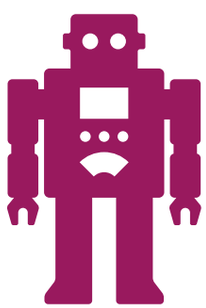
action

Internal vs. External Model

Since the agent cannot fully know the external model,
it should build an internal model itself for decision making.

internal model

agent



partial state

utility

action

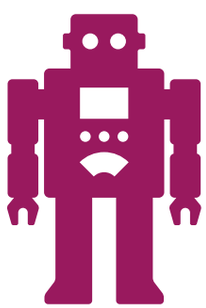
environment
external model

Internal vs. External Model

Since the agent cannot fully know the external model,
it should build an internal model itself for decision making.

internal model

agent



partial state

utility

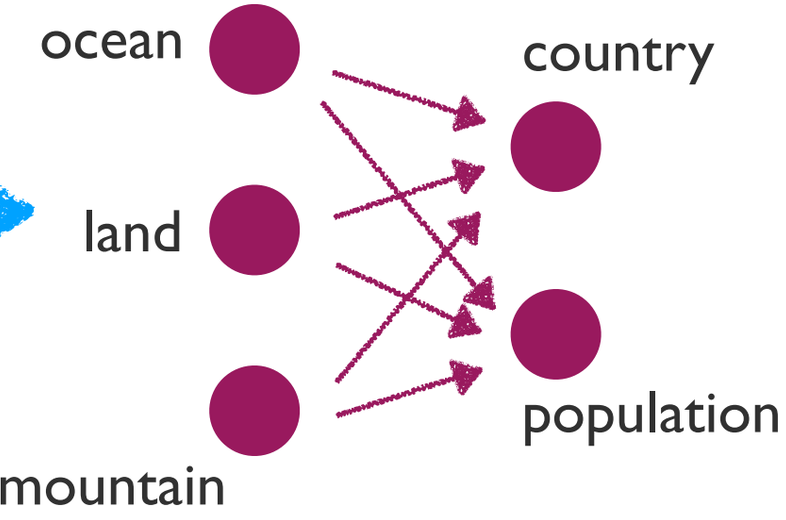
action

environment
external model

Reasoning in the Internal Model

longitude and latitude

ocean, land, mountain



- Turn primitive external states into meaningful internal states.
- Reason about most useful states for decision making.

These reasoning rules are called knowledges in an AI system.

Decision Making & Knowledge Reasoning

- We will learn three kinds of knowledge reasoning strategies:
  - logic inference, probabilistic inference, causal inference.
- Decision making & knowledge reasoning will be the first half of this course (the next 6 lectures).

The second half (6 lectures) will focus on machine learning:
Obtain the ability to do decision making and knowledge reasoning by learning from experience.

Outline

- Course Info
- What is AI?
- Three building blocks:
  - Decision making
  - Knowledge reasoning
  - Machine learning
- Two term goals
  - Decode math equations
  - Play Atari games
- Take-Home Messages

Machine Learning

Computer Program

Input	Output
numbers	sorts
graph	shortest path
random seed	pseudo-random numbers
items: {weight, value}	knapsack solution
images	classes
game	actions to play

Machine Learning

In machine learning, we want to obtain these programs (functions) by learning from experience instead of programming by hand.

Computer Program

Input	Output
numbers	sorts
graph	shortest path
random seed	pseudo-random numbers
items: {weight, value}	knapsack solution
images	classes
game	actions to play

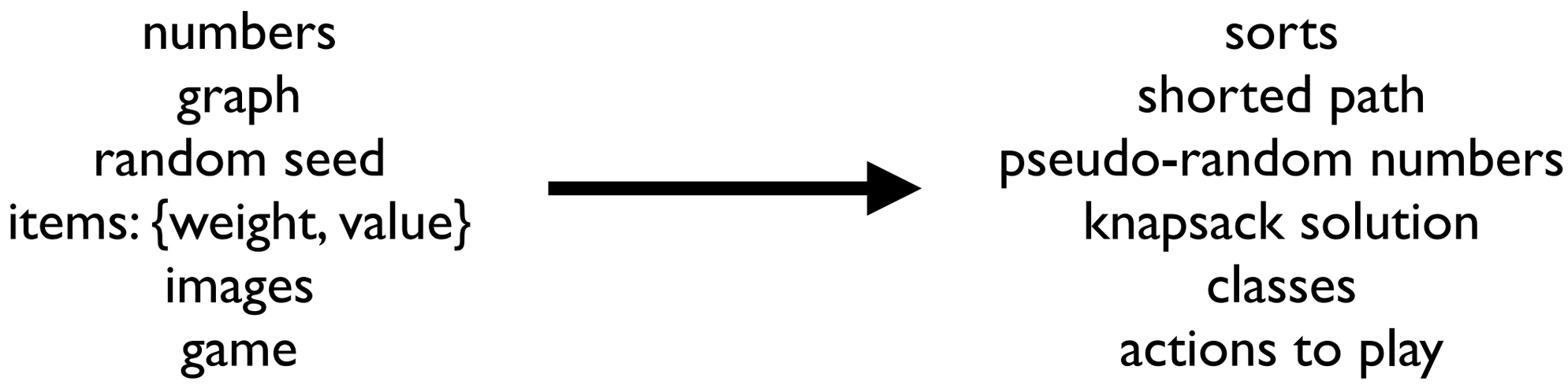
Machine Learning

numbers
graph
random seed
items: {weight, value}
images
game

sorts
shorted path
pseudo-random numbers
knapsack solution
classes
actions to play

- Do all computer programs need to be obtained by machine learning?

Machine Learning



- Do all computer programs need to be obtained by machine learning?
  - When learning is hard but programming-by-hand is easy: NO!

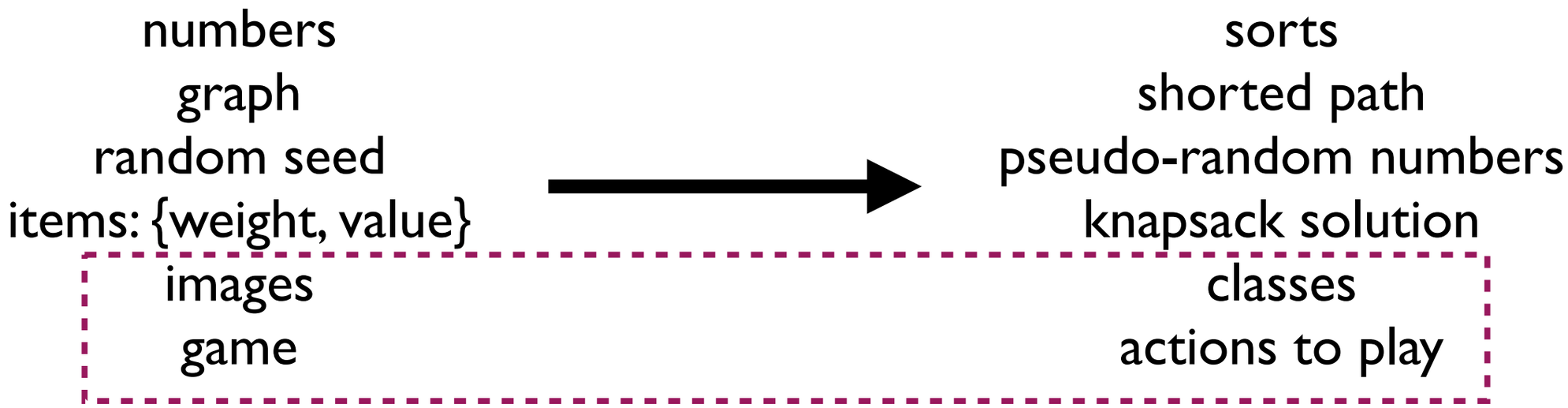
Machine Learning

numbers
graph
random seed
items: {weight, value}
images
game

sorts
shorted path
pseudo-random numbers
knapsack solution
classes
actions to play

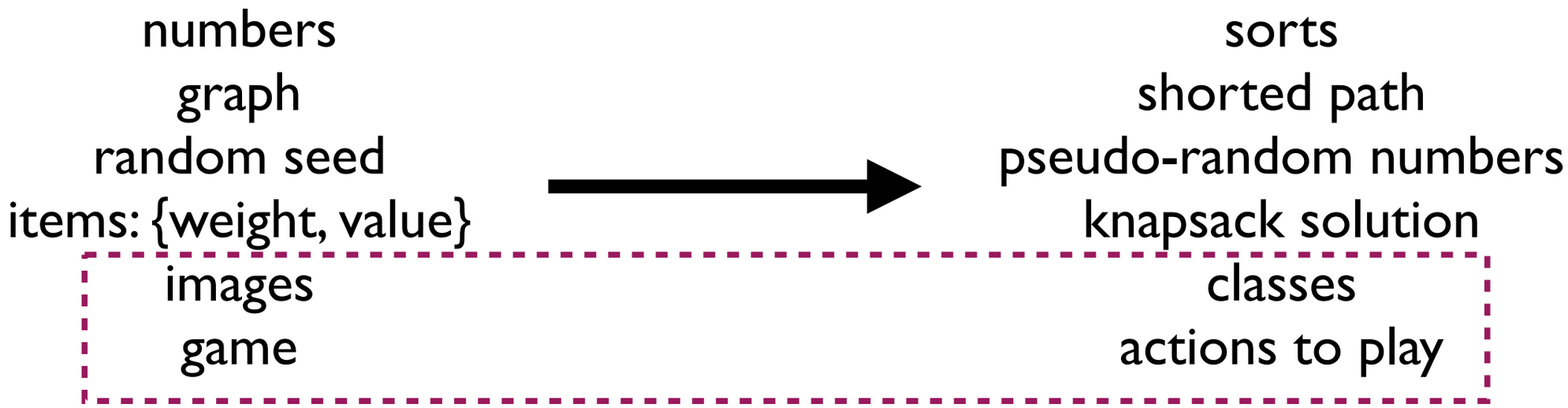
- Do all computer programs need to be obtained by machine learning?
  - When learning is hard but programming-by-hand is easy: NO!
  - When programming-by-hand is hard but learning is easy: YES!

Machine Learning



- Do all computer programs need to be obtained by machine learning?
  - When learning is hard but programming-by-hand is easy: NO!
  - When programming-by-hand is hard but learning is easy: YES!

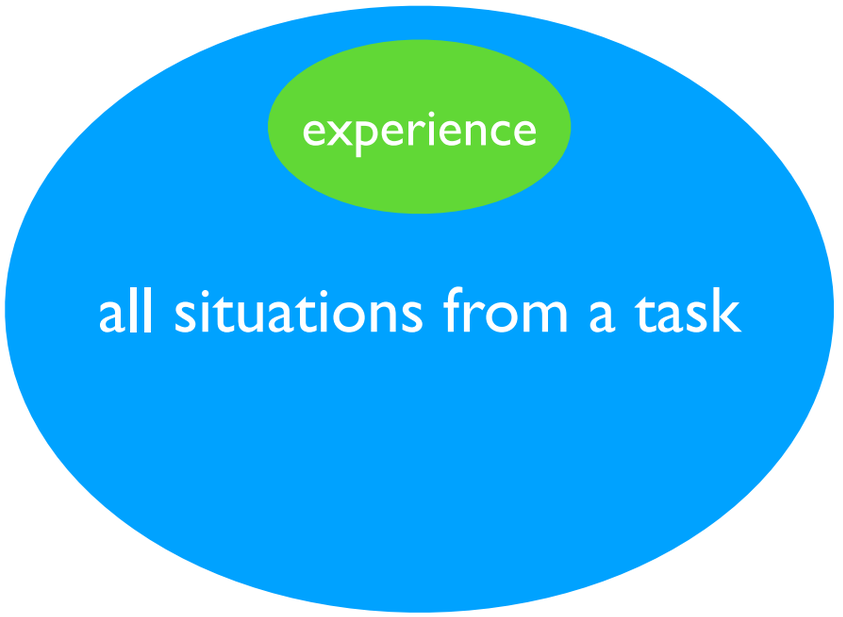
Machine Learning



- Do all computer programs need to be obtained by machine learning?
  - When learning is hard but programming-by-hand is easy: NO!
  - When programming-by-hand is hard but learning is easy: YES!

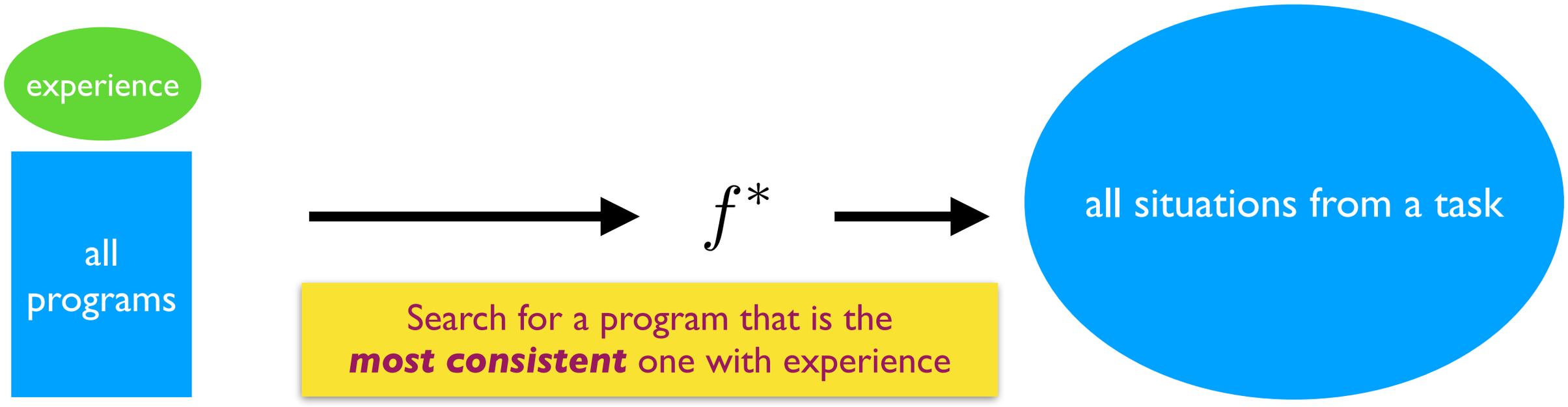
When will learning be possible?
When learning is possible, how to learn efficiently?
Similar to fundamental problems of computation.
What's the difference?

Basic Mechanism

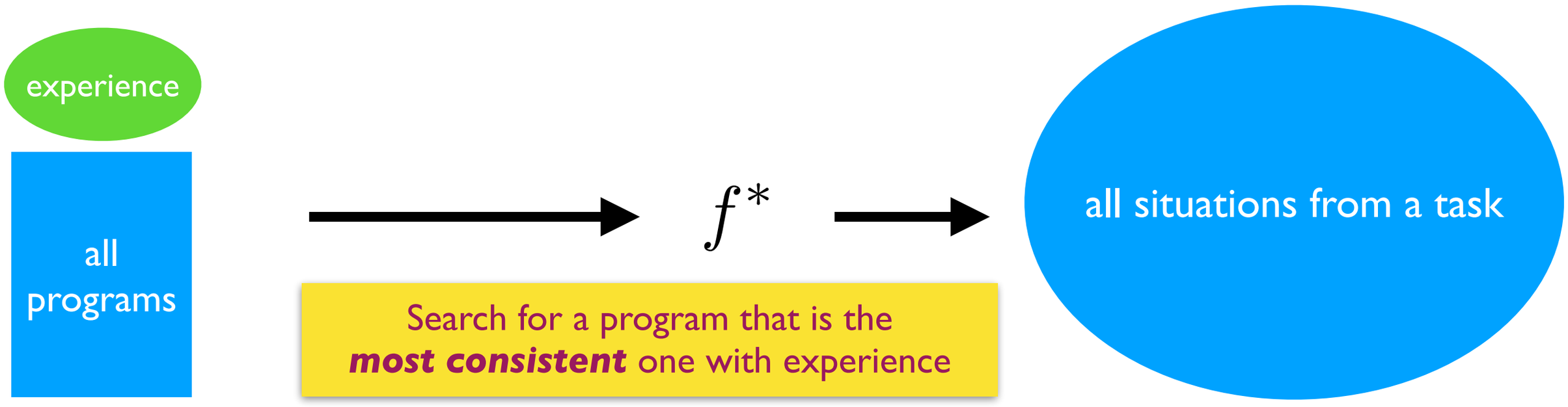


Basic Mechanism

Basic Mechanism

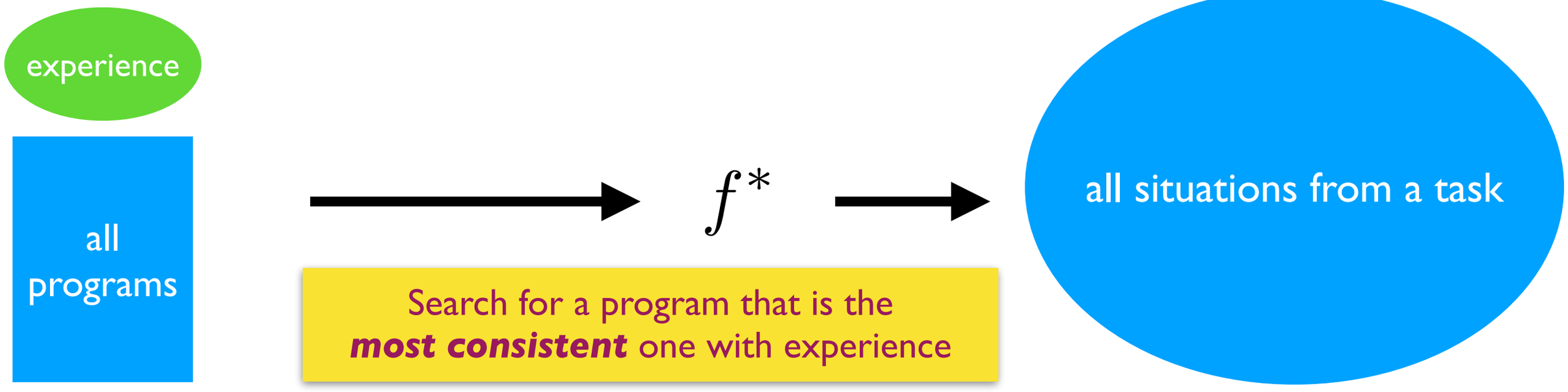


Basic Mechanism



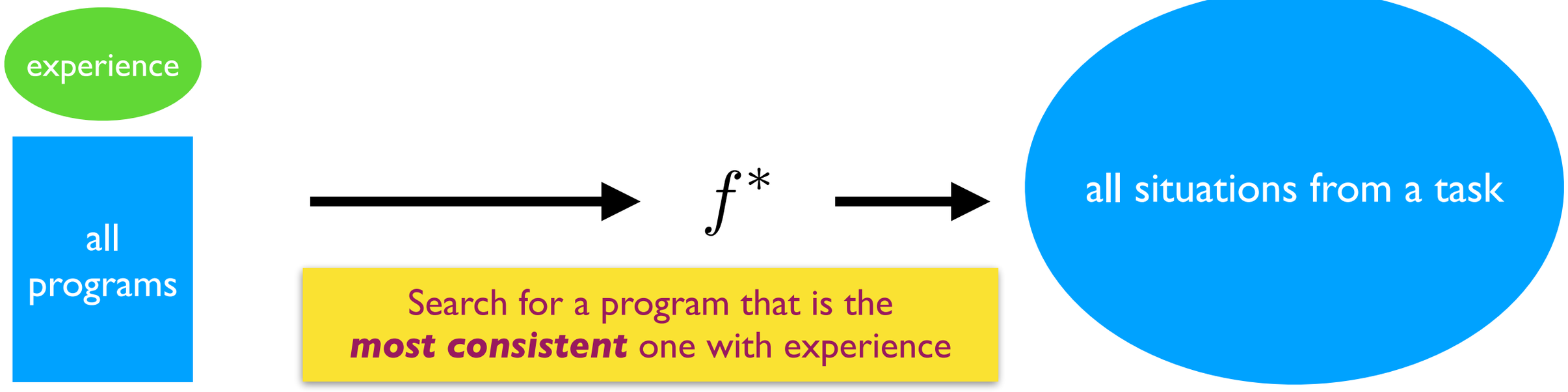
- When will learning be possible and easy?
  - When limited experience can represent all situations.
  - When searching for the best program can be done efficiently.

Machine Learning is a Statistical Problem



- When will learning be possible and easy?
  - When limited experience can represent all situations.
  - When searching for the best program can be done efficiently.

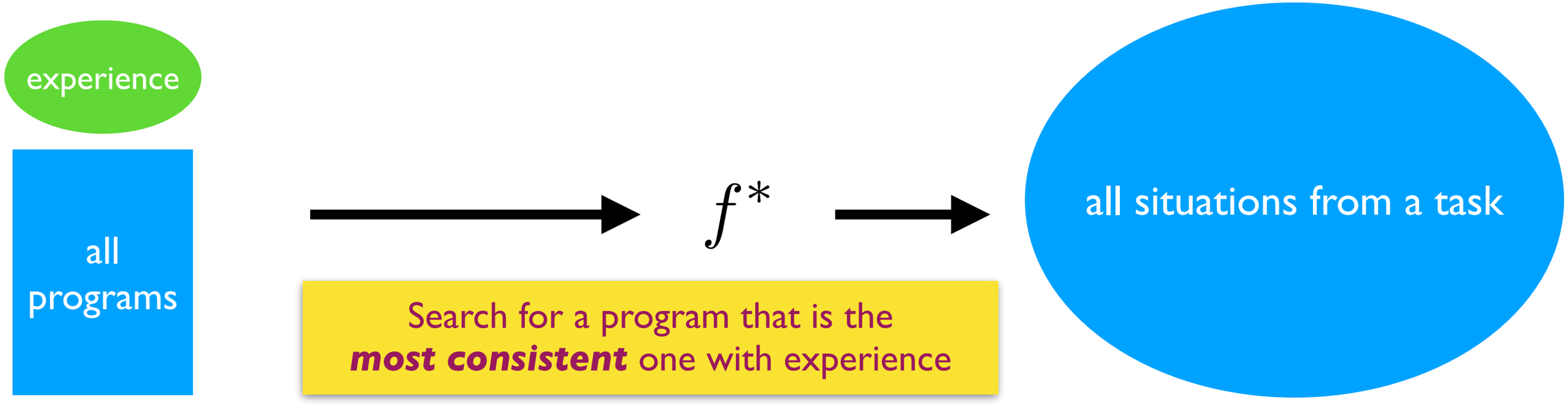
Machine Learning is a Statistical Problem



- When will learning be possible and easy?
  - When limited experience can represent all situations.
  - When searching for the best program can be done efficiently.

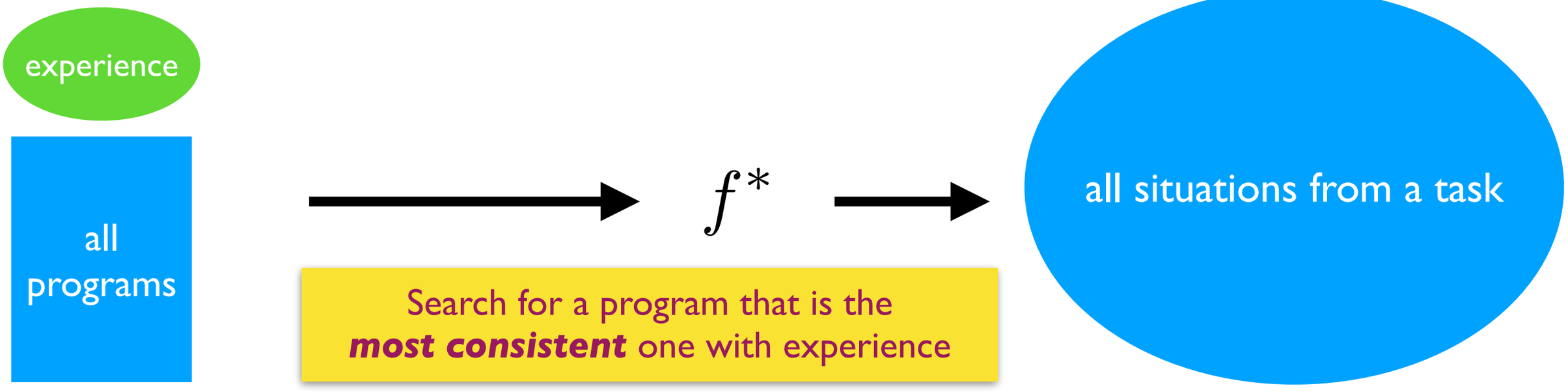
Obtain general rule from limited experiences: **statistics**.
Basic principle: the law of large numbers.

Machine Learning is a Computation Problem



- When will learning be possible and easy?
  - When limited experience can represent all situations.
  - When searching for the best program can be done efficiently.

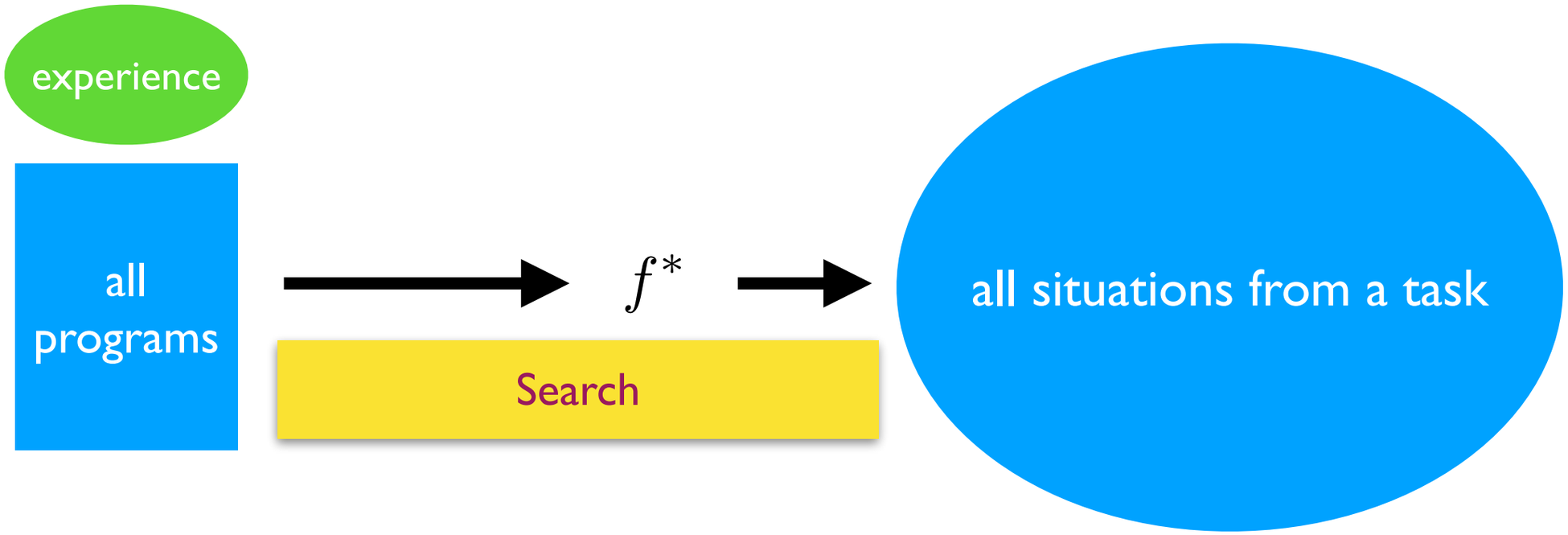
Machine Learning is a Computation Problem



- When will learning be possible and easy?
  - When limited experience can represent all situations.
  - When searching for the best program can be done efficiently.

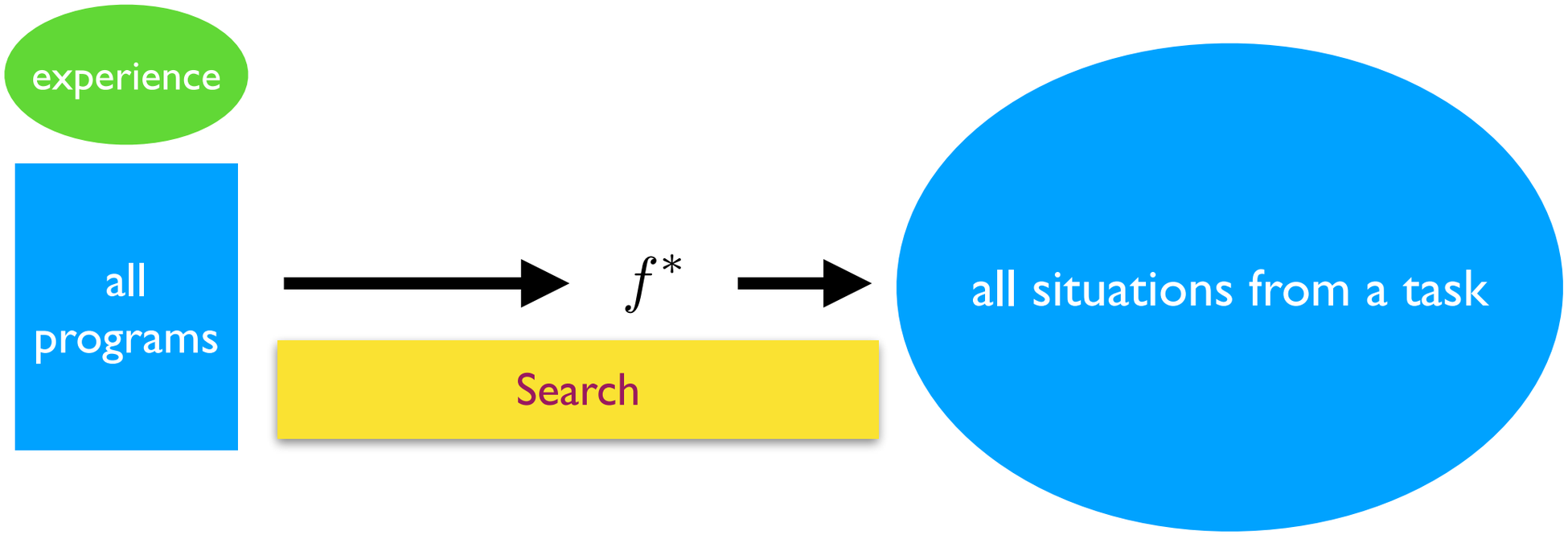
Searching from the optimal solution: **Optimization**.
Optimization is a computation problem.

Inductive Bias in Machine Learning



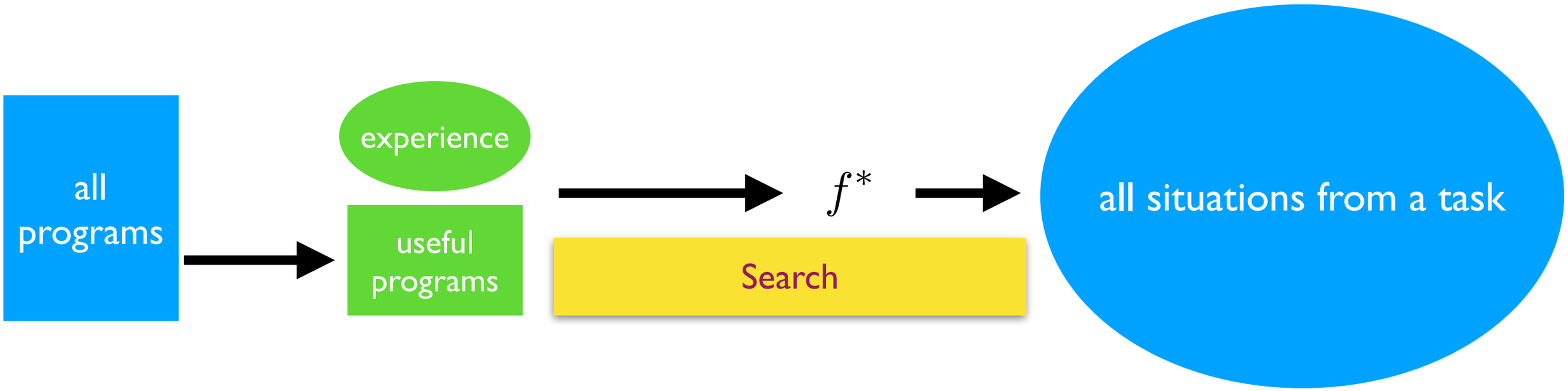
- Learning is both statistical and computational.
  - We care about both statistical and computational complexity.

Inductive Bias in Machine Learning



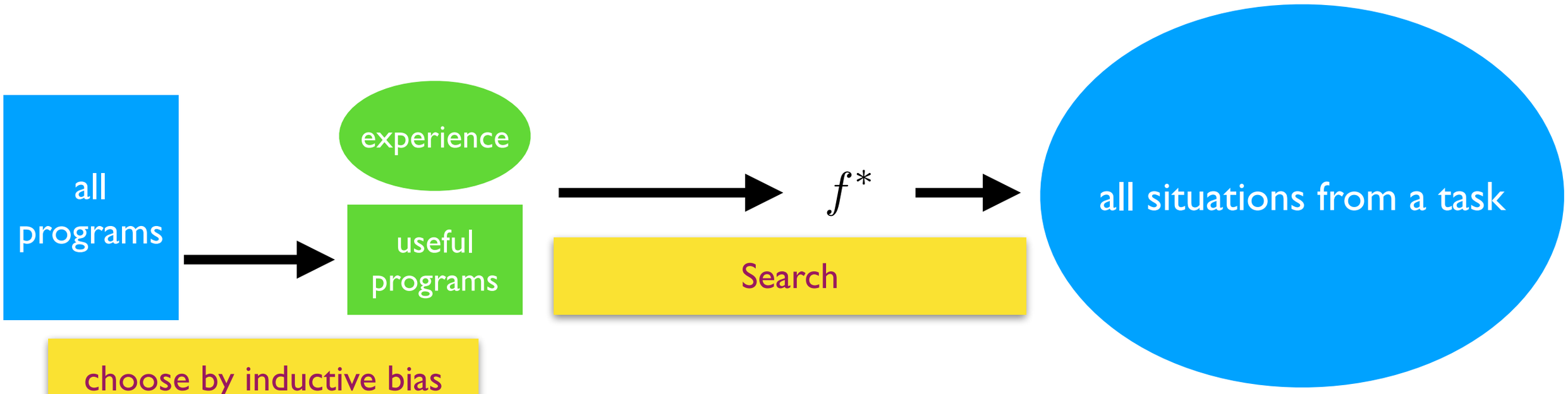
- Learning is both statistical and computational.
  - We care about both statistical and computational complexity.
  - Humans can learn from very few experiences and very fast. Why?

Inductive Bias in Machine Learning



- Learning is both statistical and computational.
  - We care about both statistical and computational complexity.
  - Humans can learn from very few experiences and very fast. Why?

Inductive Bias in Machine Learning



- Learning is both statistical and computational.
  - We care about both statistical and computational complexity.
  - Humans can learn from very few experiences and very fast. Why?

Not all programs are born equal.
Humans choose the right **inductive bias** to reduce the program set.

Machine Learning: Theory, Algorithm, and Application

- Machine Learning Theory:
  - Understanding the foundations: when will learning be easy?

theoretical computer science, statistics, game theory, information theory…

- Machine Learning Algorithm:
  - Design models and algorithms for *general* machine learning problems.
- Machine Learning Application:
  - Design inductive bias for different applications, e.g. CV, NLP.

Machine Learning Scenarios

- Supervised learning
  - Classification
  - Regression
  - Ranking
- Unsupervised learning
  - Clustering, density estimation
  - Generative modeling
- Semi-supervised learning
- Reinforcement learning  learn from self-generated data
- …

Machine Learning Methods

- Symbolic Learning
- Frequentist statistical learning
  - Support vector machine, kernel method
  - Decision tree, random forest, boosting
- Bayesian statistical learning
  - Graphical models
  - Variational inference and approximate sampling
- Neural networks
  - Deep learning

Machine Learning Methods

- Symbolic Learning
- Frequentist statistical learning
  - Support vector machine, kernel method
  - Decision tree, random forest, boosting
- Bayesian statistical learning
  - Graphical models
  - Variational inference and approximate sampling
- Neural networks
  - Deep learning

No absolute boundaries!

Outline

- Course Info
- What is AI?
- Three building blocks:
  - Decision making
  - Knowledge reasoning
  - Machine learning
- Two term goals
  - Decode math equations
  - Play Atari games
- Take-Home Messages

Lab Projects

- 4 lab projects:
  - Search
  - Knowledge reasoning
  - Supervised/unsupervised learning
  - Reinforcement learning

Lab Projects

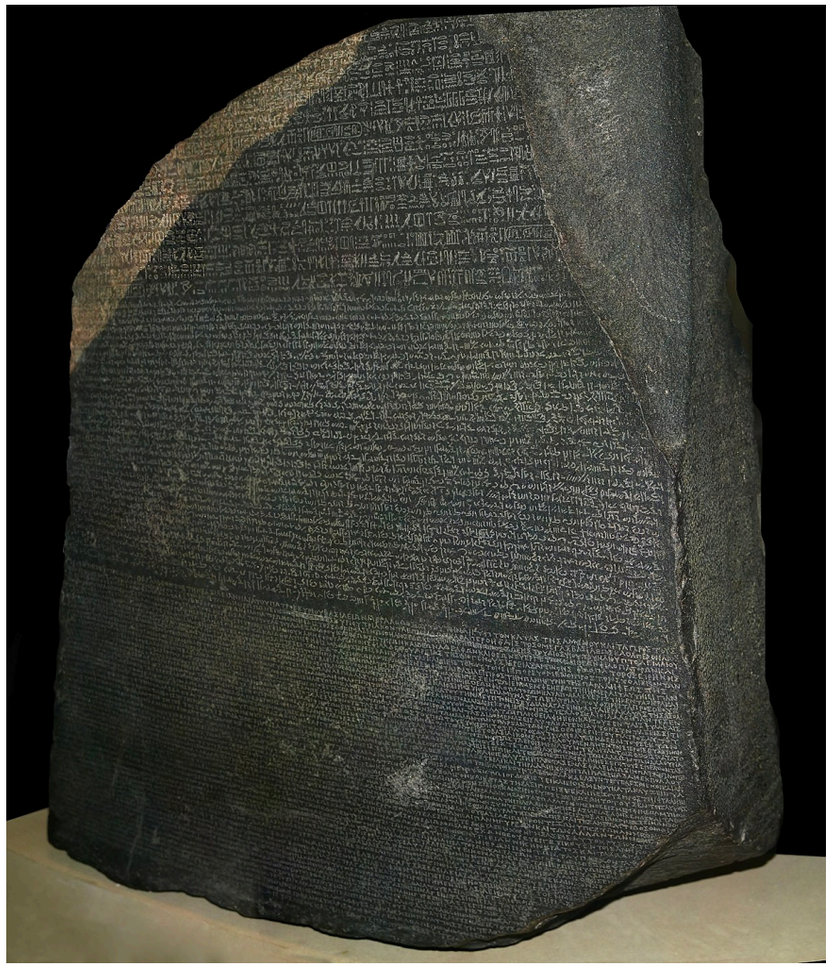
- 4 lab projects:
  - Search
  - Knowledge reasoning
  - Supervised/unsupervised learning
  - Reinforcement learning

We expect that after learning this course,
you are able to build one of the following two systems!
(and get the bonus scores :-P)

Outline

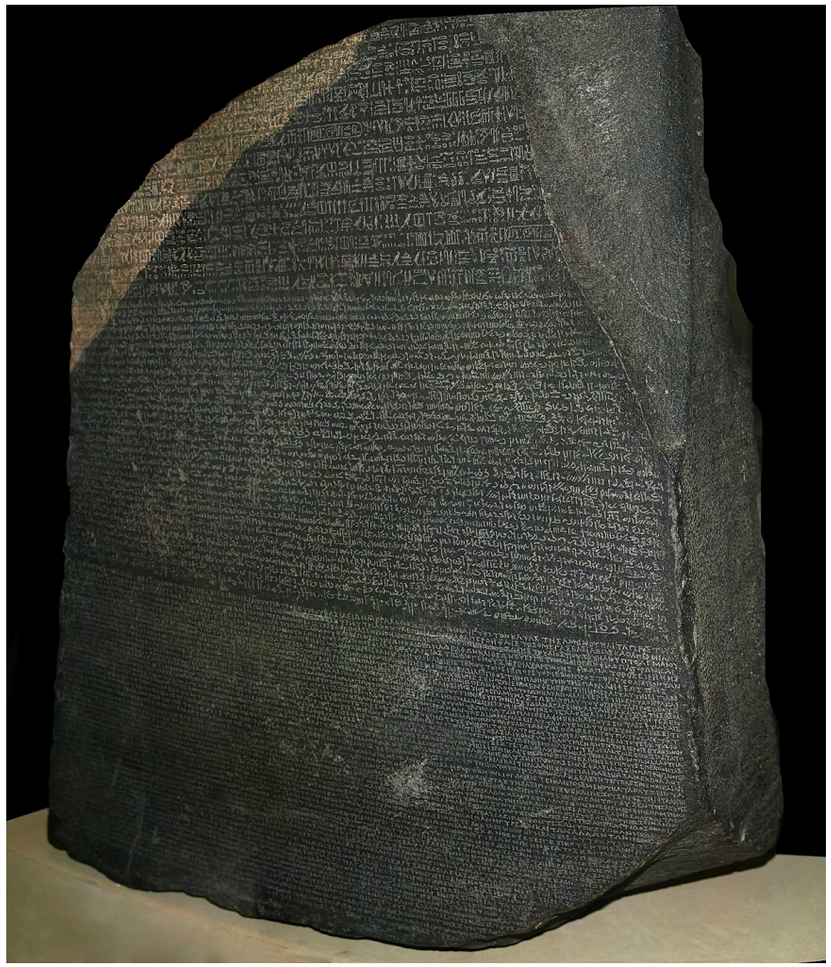
- Course Info
- What is AI?
- Three building blocks:
  - Decision making
  - Knowledge reasoning
  - Machine learning
- Two term goals
  - Decode math equations
  - Play Atari games
- Take-Home Messages

Imaging You Are an Archaeologist…

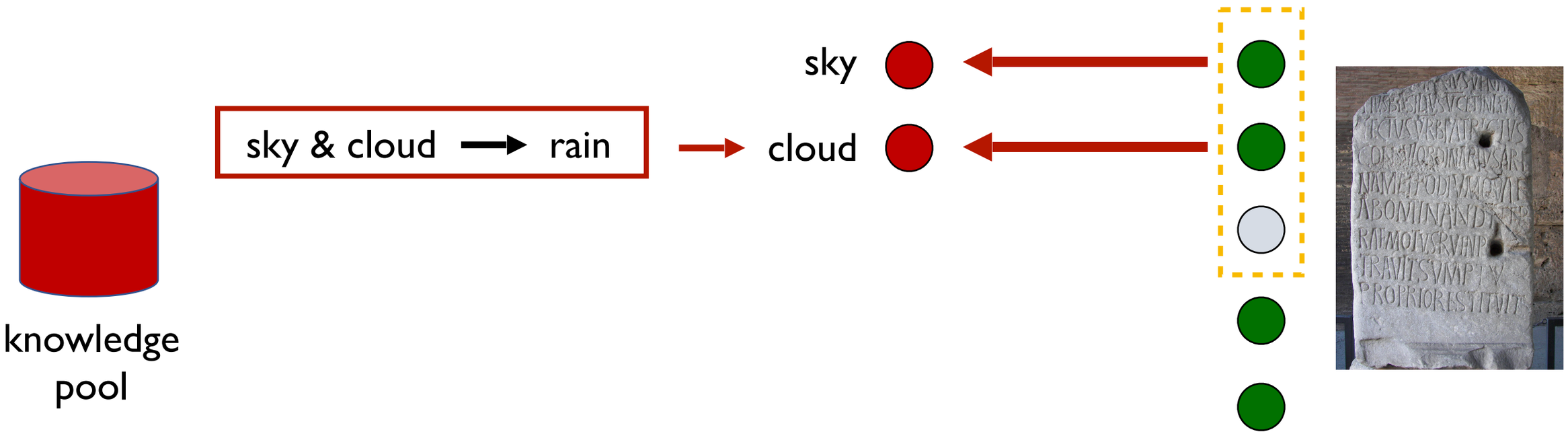


Imaging You Are an Archaeologist…

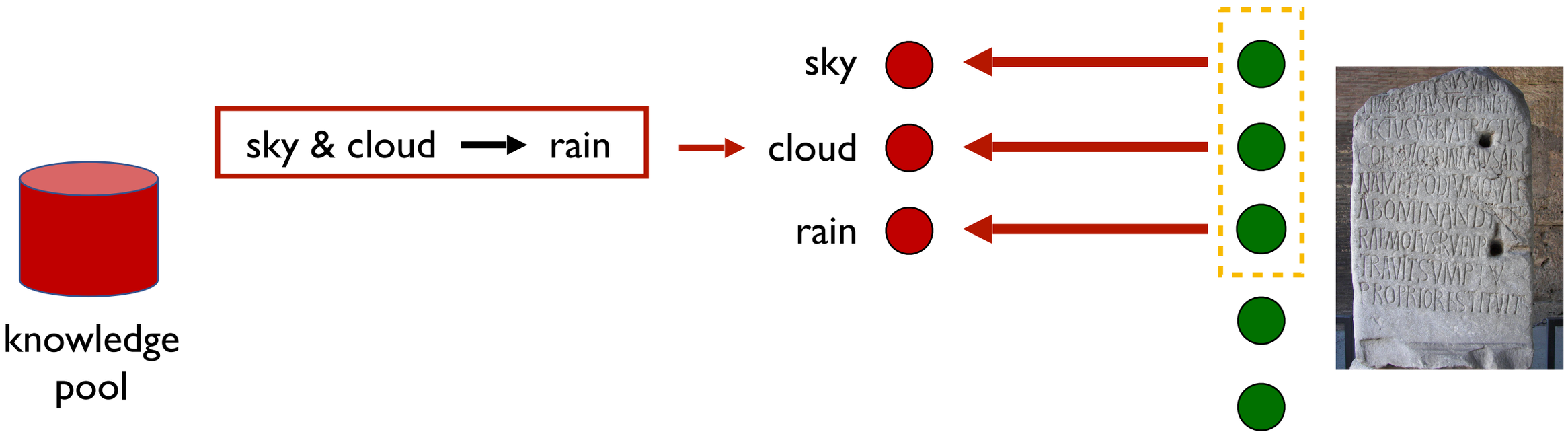
How you decode these characters?



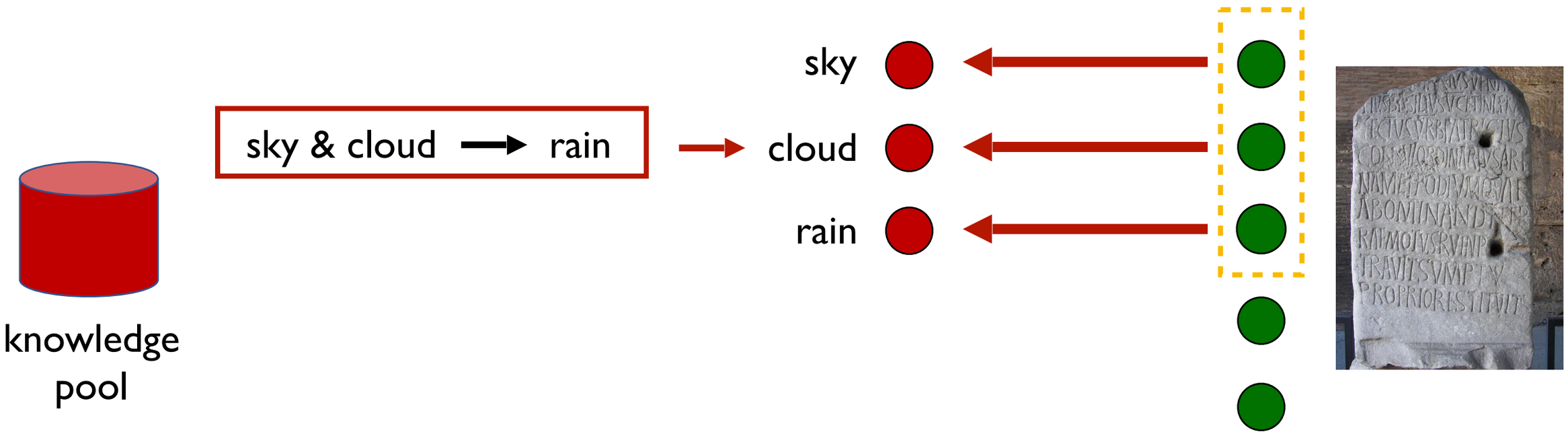
Decoding via Reasoning & Learning



Decoding via Reasoning & Learning

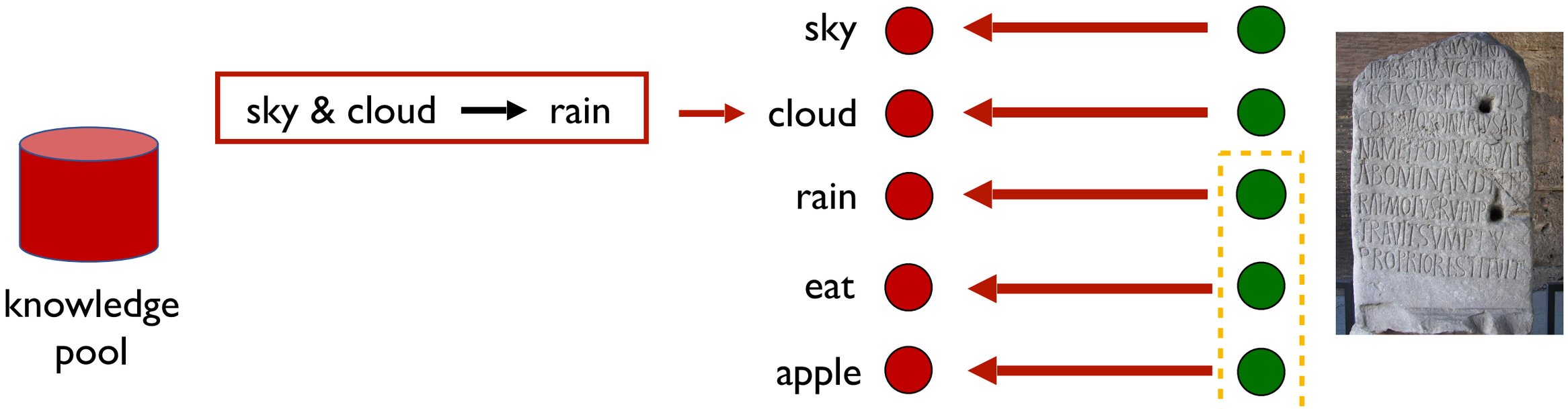


Decoding via Reasoning & Learning



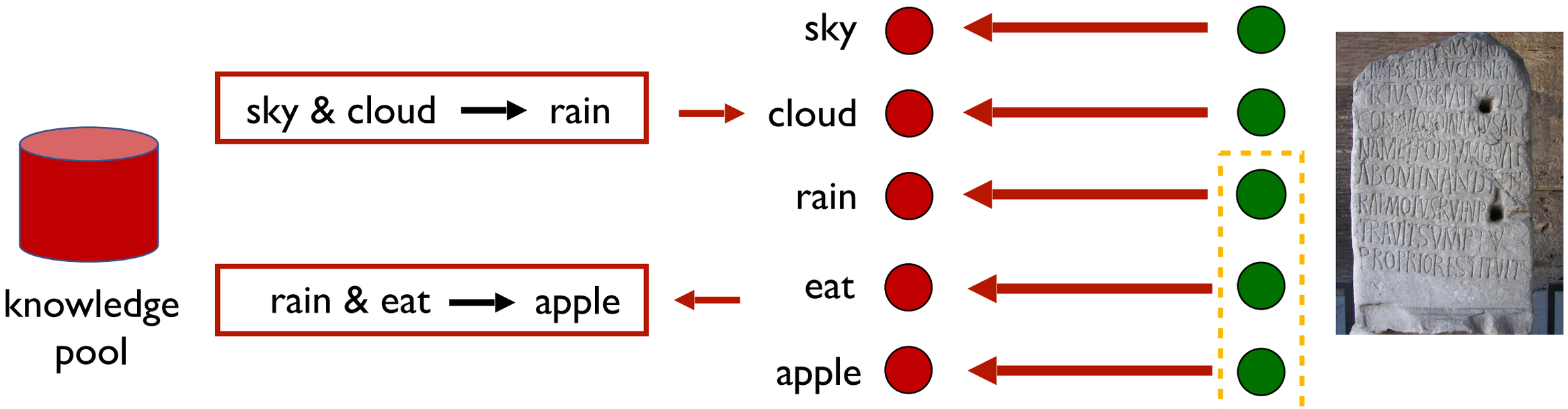
- Supervise character recognition by knowledge rules

Decoding via Reasoning & Learning



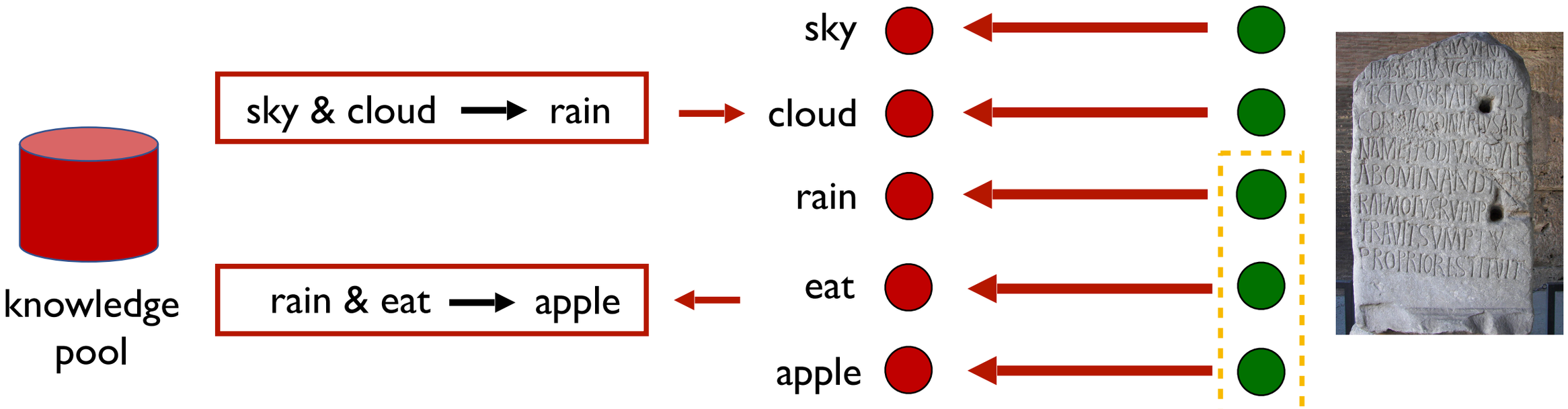
- Supervise character recognition by knowledge rules

Decoding via Reasoning & Learning



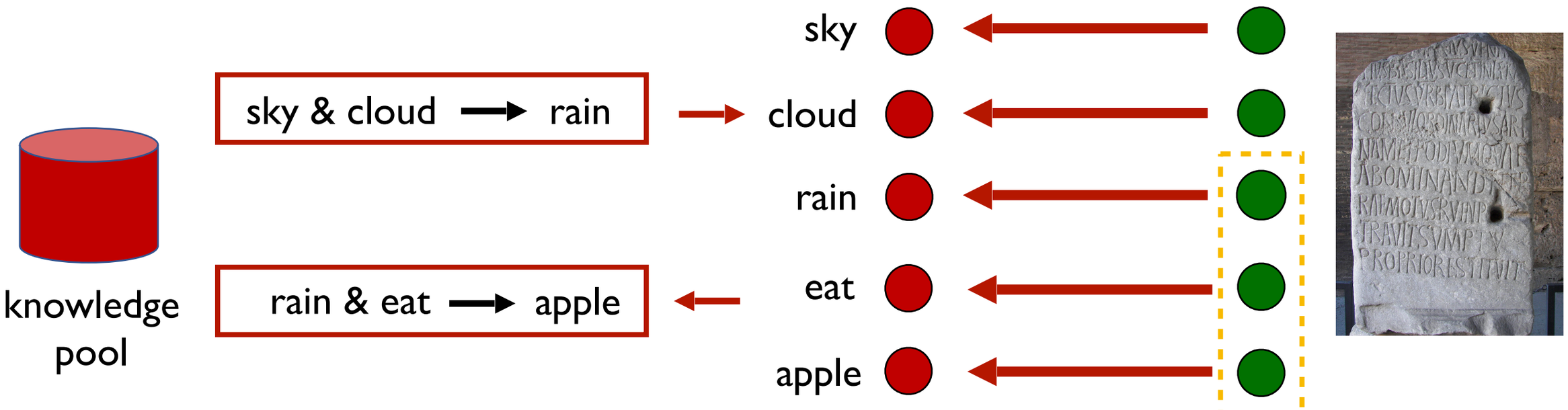
- Supervise character recognition by knowledge rules

Decoding via Reasoning & Learning



- Supervise character recognition by knowledge rules
- Learn new knowledge rules from recognition result

Decoding via Reasoning & Learning



- Supervise character recognition by knowledge rules
- Learn new knowledge rules from recognition result

Bridge knowledge learning, reasoning and low-level perception learning.
A frontier of machine learning research.

Decoding Math Equations

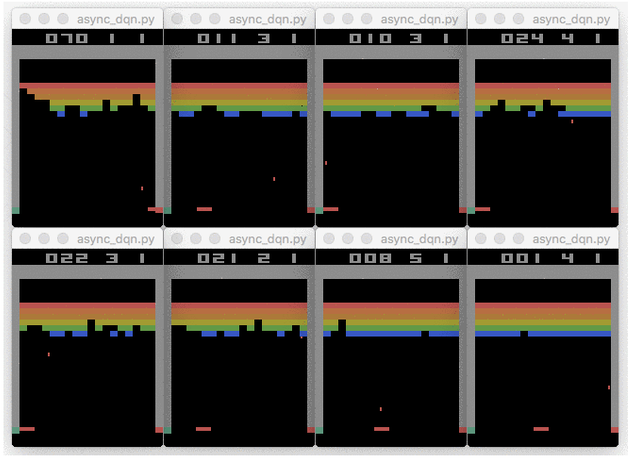
Don’t be afraid.
You AI will not need to be an archaeologist.
It just needs to be a primary school student. :-P

Outline

- Course Info
- What is AI?
- Three building blocks:
  - Decision making
  - Knowledge reasoning
  - Machine learning
- Two term goals
  - Decode math equations
  - Play Atari games
- Take-Home Messages

Reinforcement Learning

- Reinforcement Learning is learning to make decisions.

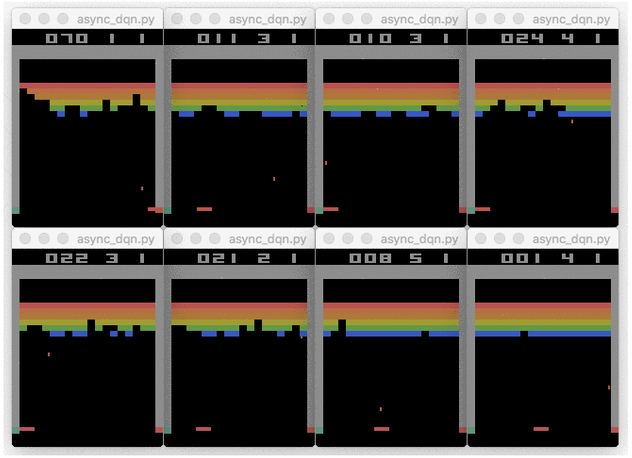


- The agent faces a series of states.
- Need to choose the corresponding actions.
- Target: maximize the total reward.

The agent learns from self-generated data in the world.

Reinforcement Learning

- Reinforcement Learning is learning to make decisions.

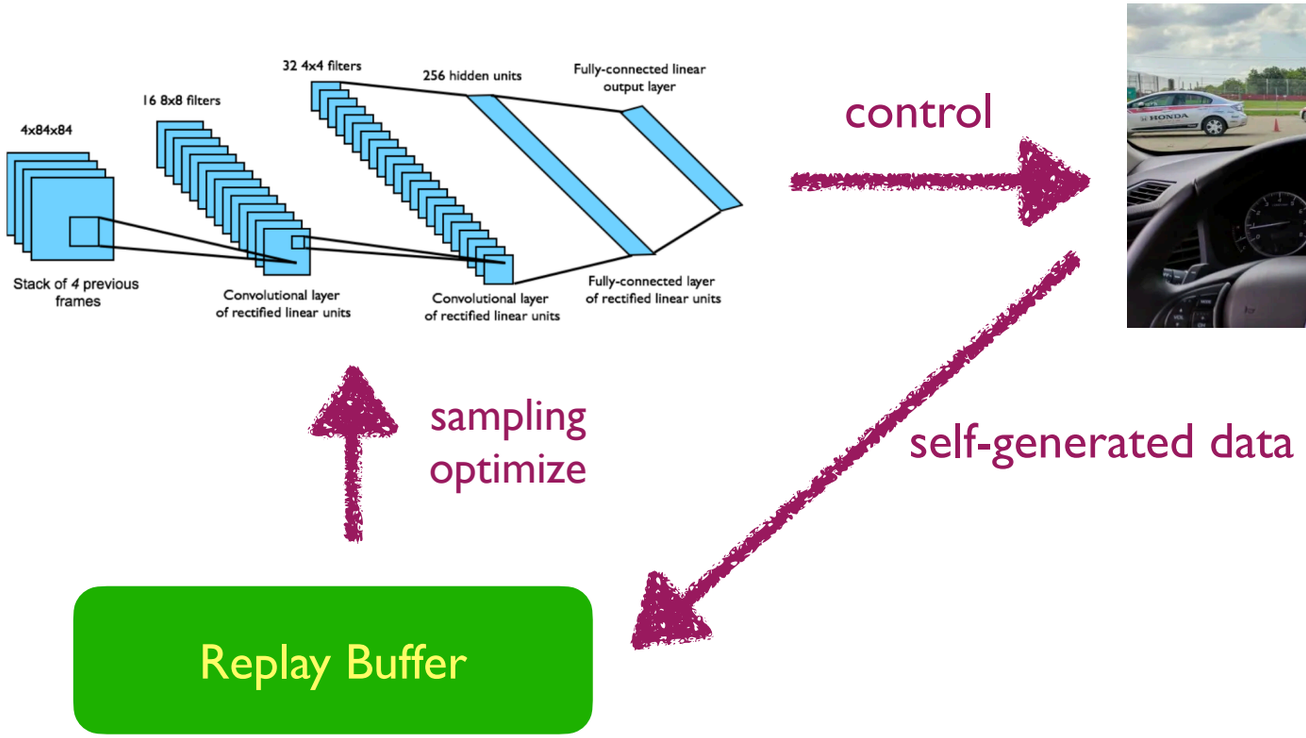


- The agent faces a series of states.
- Need to choose the corresponding actions.
- Target: maximize the total reward.

The agent learns from self-generated data in the world.

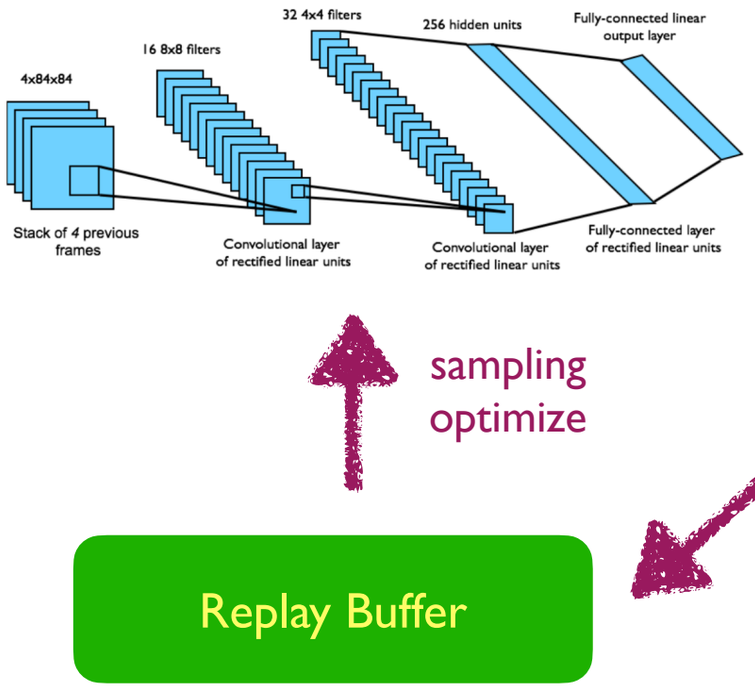
Why hasn't DRL solved many real-world problems?

- Deep RL usually does not use (learn) a world model.



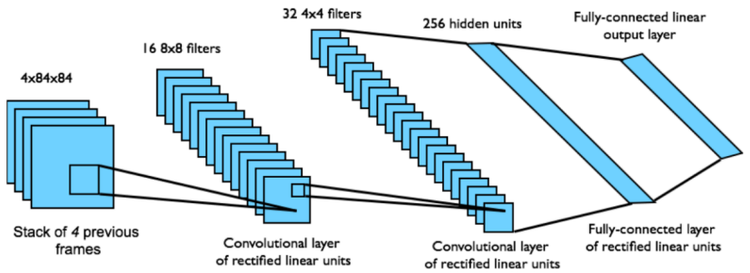
Why hasn't DRL solved many real-world problems?

- Deep RL usually does not use (learn) a world model.

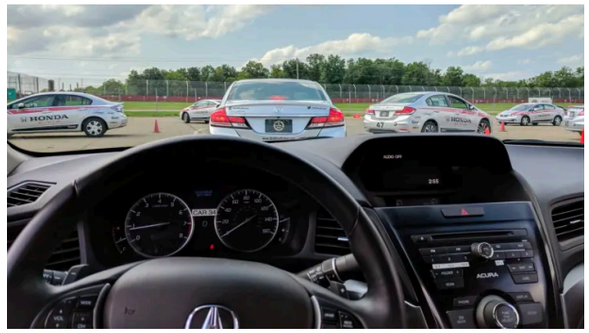


Why hasn't DRL solved many real-world problems?

- Deep RL usually does not use (learn) a world model.



control



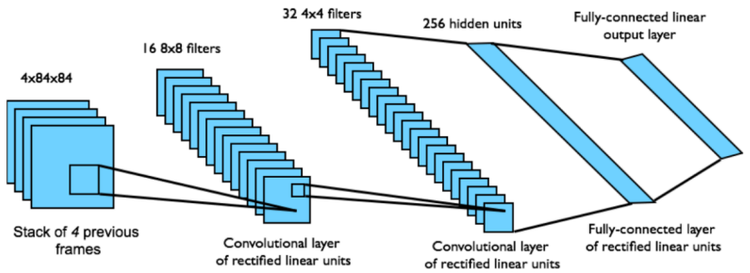
sampling
optimize

self-generated data

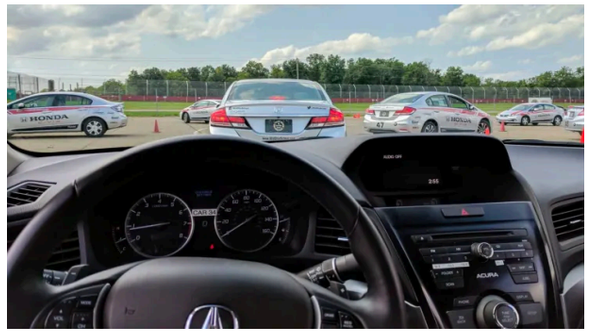
Replay Buffer

Why hasn't DRL solved many real-world problems?

- Deep RL usually does not use (learn) a world model.



control



sampling
optimize

self-generated data

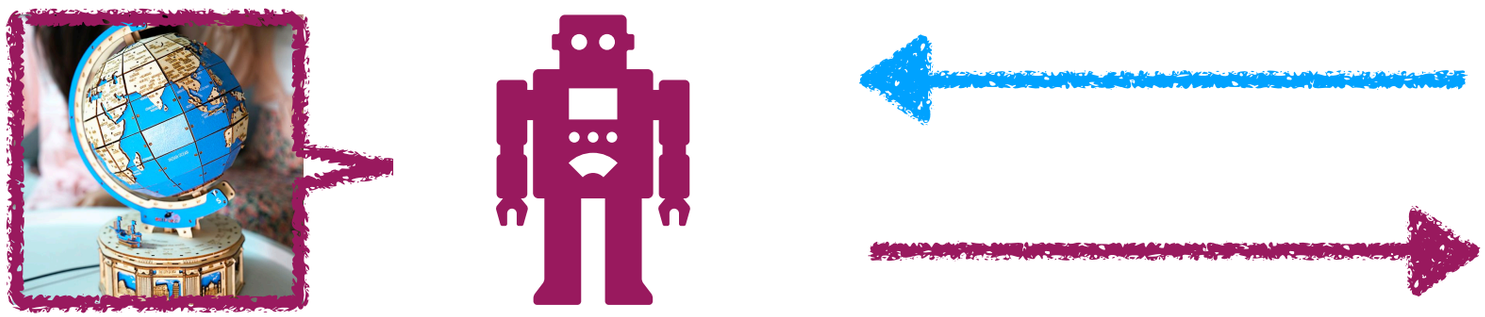
Replay Buffer

?

Without a world model, learning from self-generated data requires many trial-and-errors in the real world.
Large cost. Bad generalization to new task.

Reinforcement Learning with Models

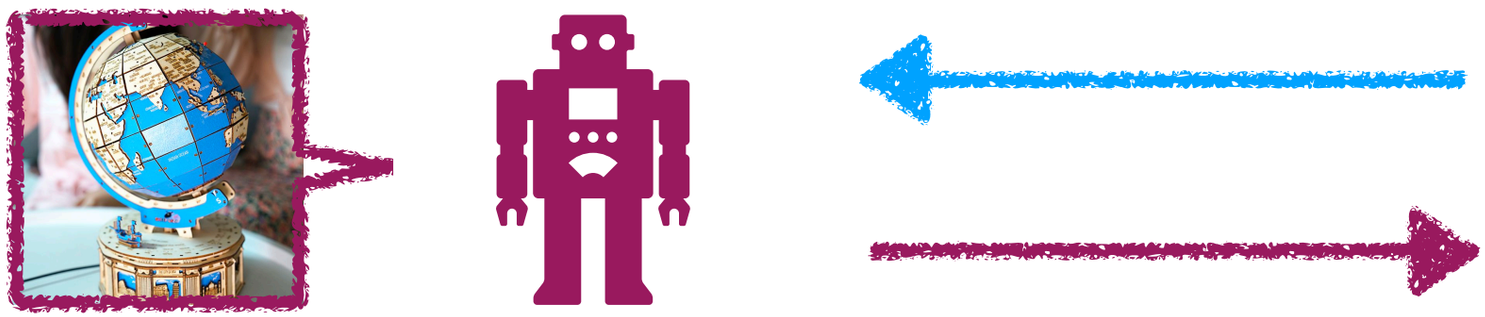
Scenarios of decision making:



Reinforcement Learning with Models

Scenarios of decision making:

- Planning: directly solve the optimal policy when the world model is known (dynamic programming, Monte-Carlo tree search…)

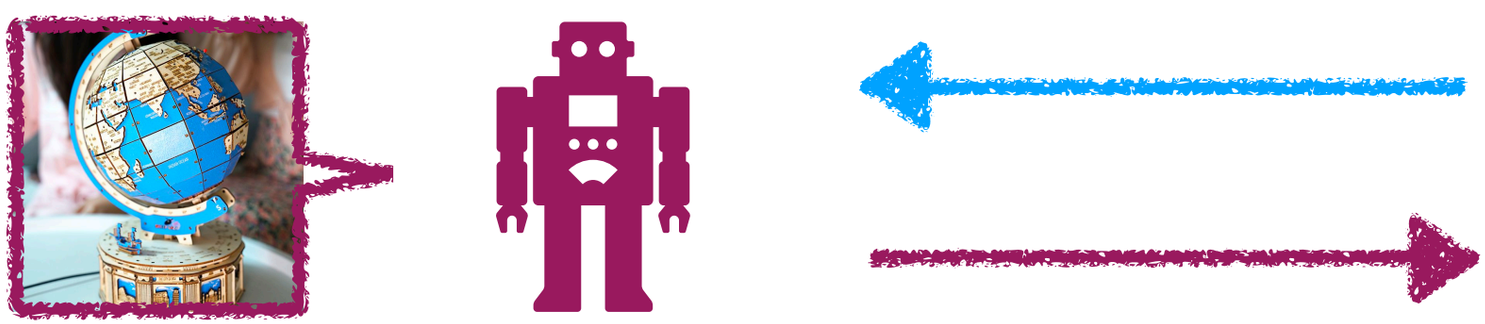


Reinforcement Learning with Models

Scenarios of decision making:

- Planning: directly solve the optimal policy when the world model is known (dynamic programming, Monte-Carlo tree search…)

- Model-free RL: learn by trial-and-error (Q-learning, policy gradient, actor-critic…)



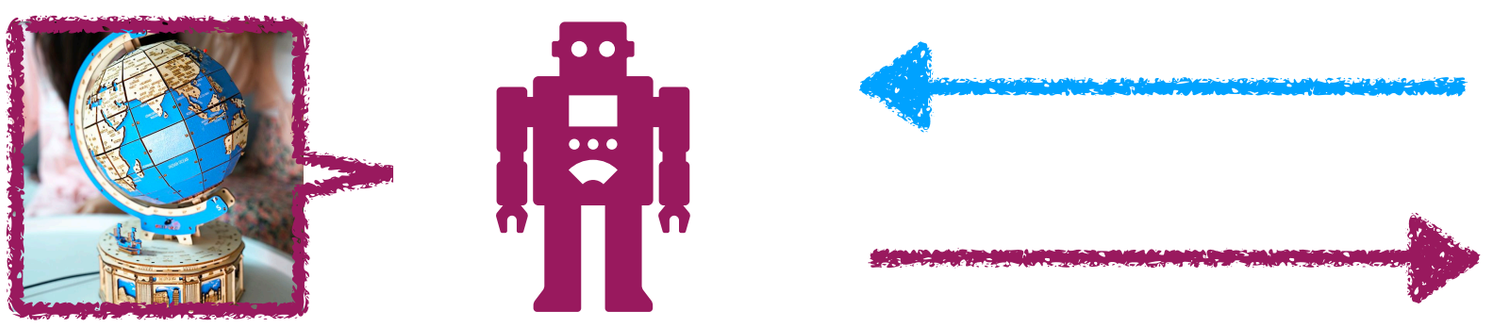
Reinforcement Learning with Models

Scenarios of decision making:

- Planning: directly solve the optimal policy when the world model is known (dynamic programming, Monte-Carlo tree search…)

- Model-free RL: learn by trial-and-error (Q-learning, policy gradient, actor-critic…)

- Model-based RL: learn the world model during learning, do RL or planning using the model.



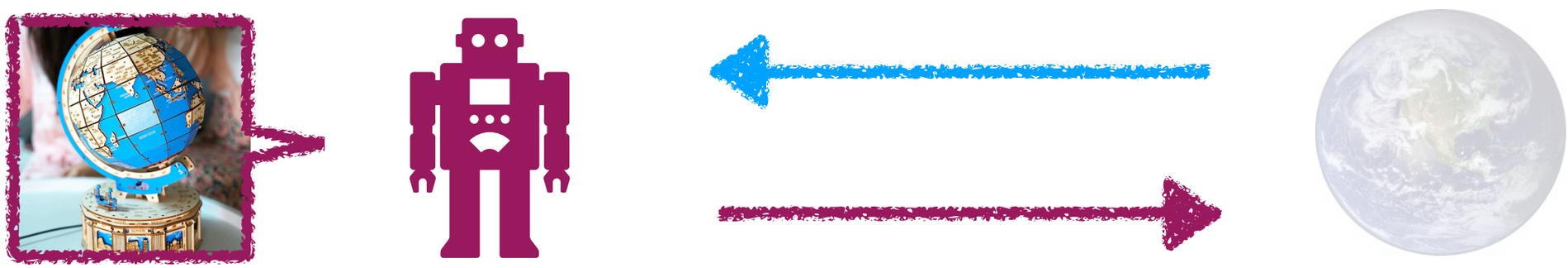
Reinforcement Learning with Models

Scenarios of decision making:

- Planning: directly solve the optimal policy when the world model is known (dynamic programming, Monte-Carlo tree search…)

- Model-free RL: learn by trial-and-error (Q-learning, policy gradient, actor-critic…)

- Model-based RL: learn the world model during learning, do RL or planning using the model.



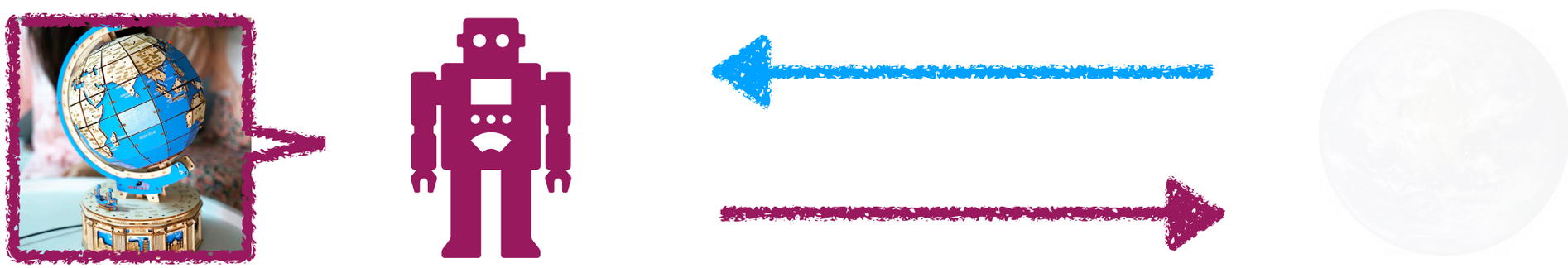
Reinforcement Learning with Models

Scenarios of decision making:

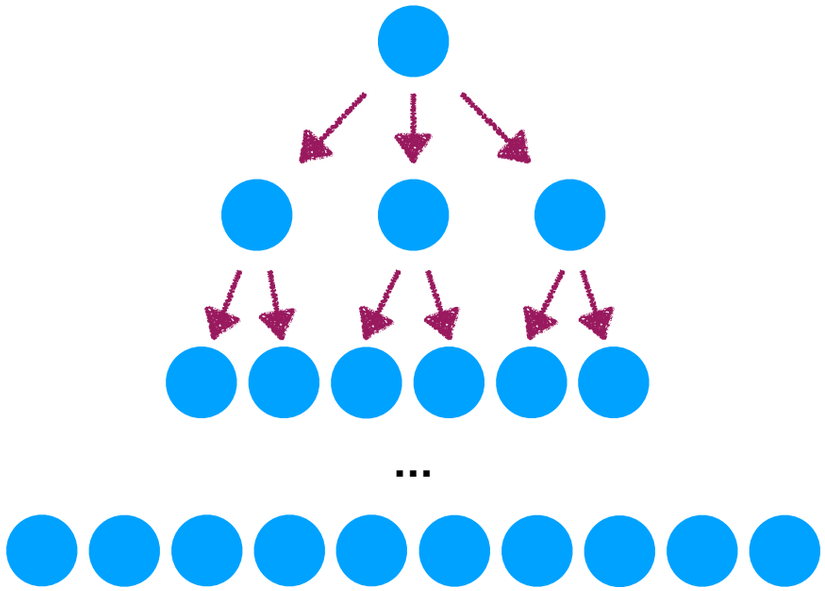
- Planning: directly solve the optimal policy when the world model is known (dynamic programming, Monte-Carlo tree search…)

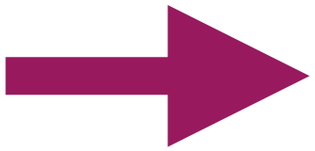
- Model-free RL: learn by trial-and-error (Q-learning, policy gradient, actor-critic…)

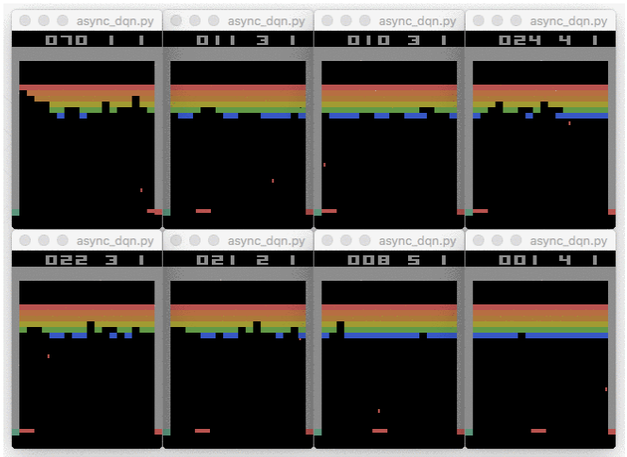
- Model-based RL: learn the world model during learning, do RL or planning using the model.

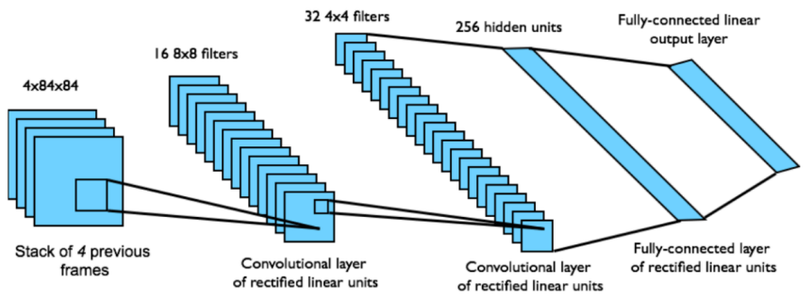


Playing Atari Games by Both Planning & Learning

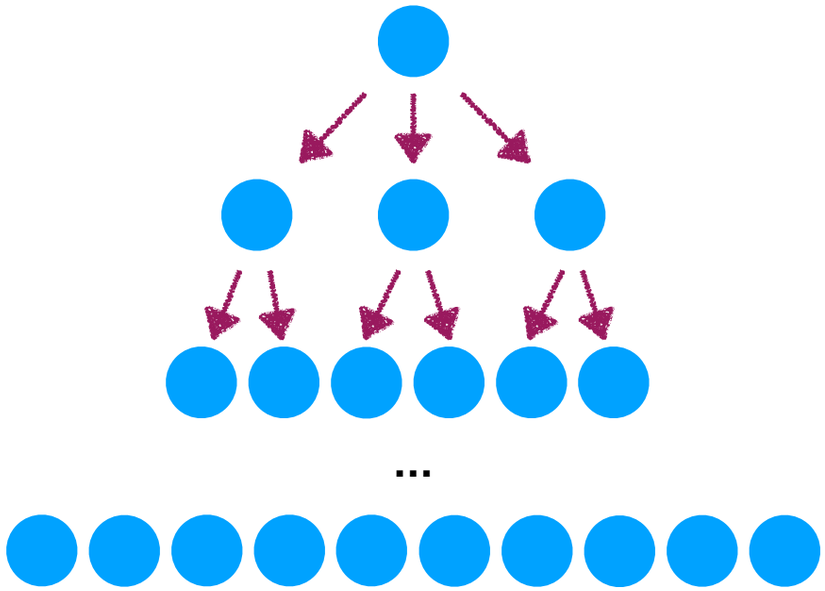


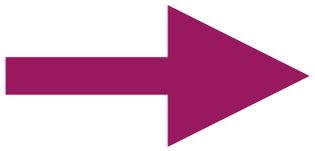


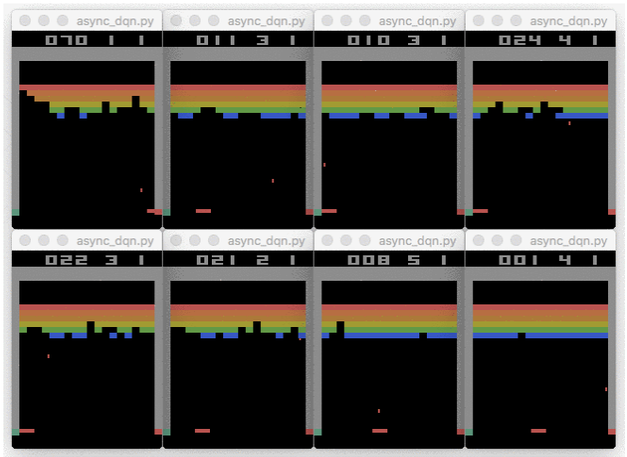


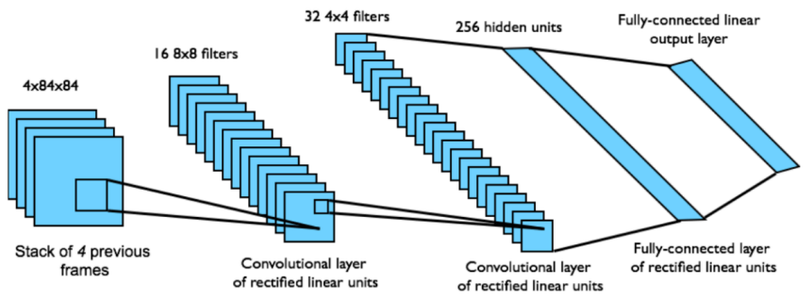


Playing Atari Games by Both Planning & Learning

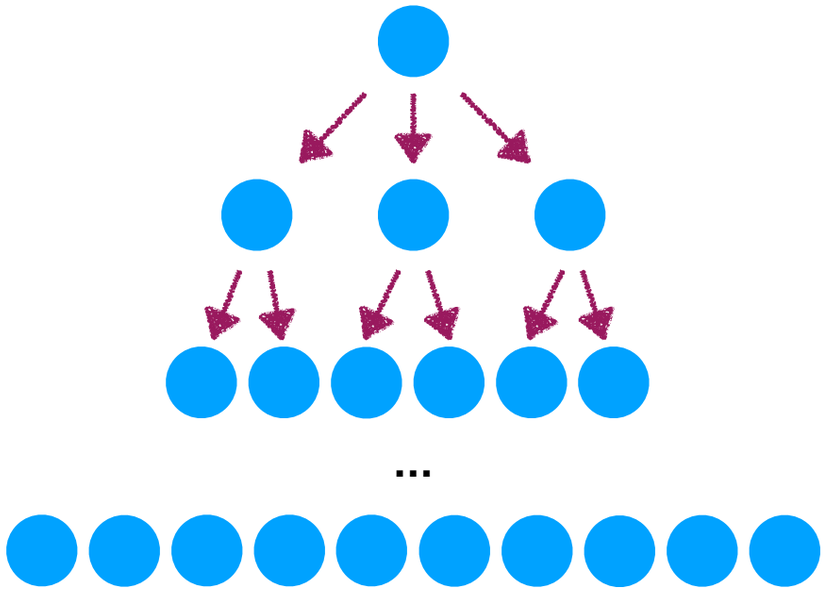


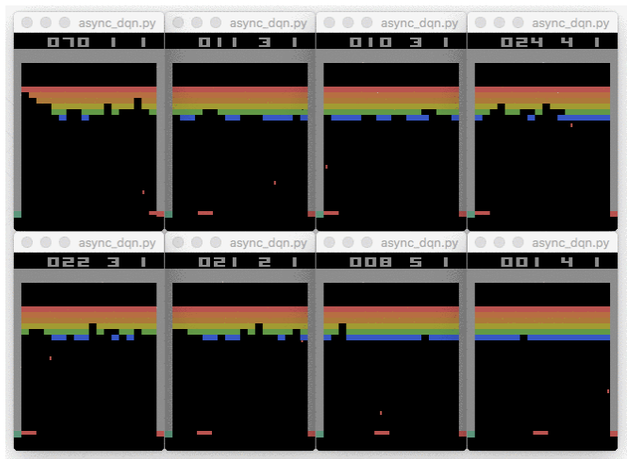


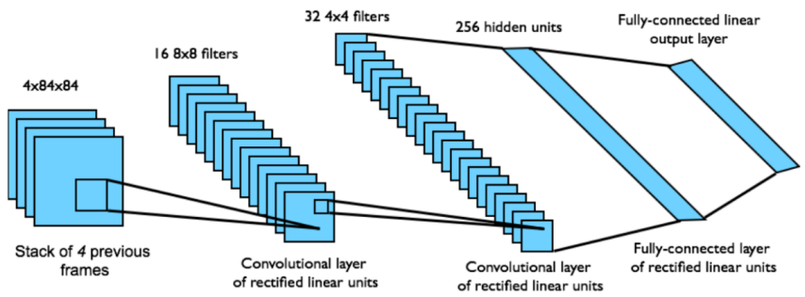




Playing Atari Games by Both Planning & Learning







Basic strategy behind many state-of-the-art decision-making AIs.
The key challenge lies in building a good internal model.

Outline

- Course Info
- What is AI?
- Three building blocks:
  - Decision making
  - Knowledge reasoning
  - Machine learning
- Two term goals
  - Decode math equations
  - Play Atari games
- Take-Home Messages

Take-Home Messages

- AI ≠ machine learning
- machine learning ≠ deep learning
- What will be covered in this course:
  - Decision making, knowledge reasoning, machine learning
- We try to study the techniques to build the following two agents:
  - Obtain insightful knowledges via their own imperfect perceptions.
  - Make rational decisions in a complicated and uncertain world.

Thanks for your attention!

Discussions?